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Costs, Benefits and Methods of Including Tire Inflation in State Vehicle Inspection Programs

Booz-Allen and Hamilton, Inc.
Bethesda, MD

Prepared for

Environmental Protection Agency
Ann Arbor, MI

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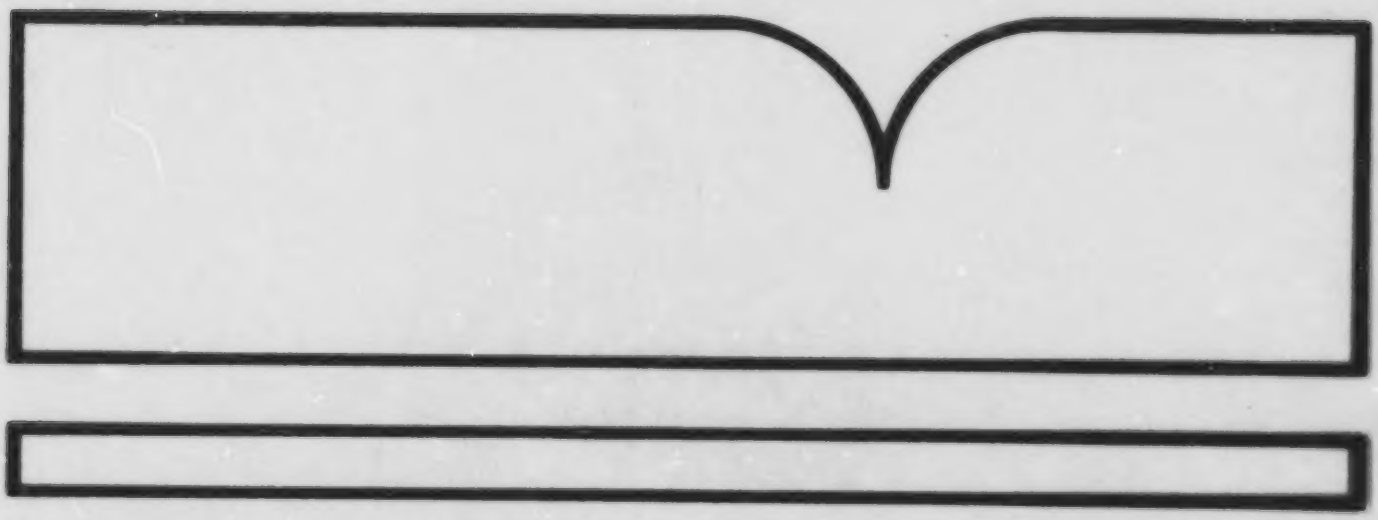

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COSTS, BENEFITS AND METHODS OF INCLUDING TIRE INFLATION IN STATE VEHICLE INSPECTION PROGRAMS

by

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This report presents information to help state include a tire inflation check in their existing and planned emissions, safety and combined safety and emissions inspection programs. It has been estimated that as much as 515 million gallons of gasoline are wasted in the United States each year due to improper tire inflation. Tire inflation if added to a state motor vehicle inspection program would help motorists increase vehicle fuel economy and reduce tire wear as well as improve safety. States adding tire inflation to inspection programs would be able to reduce the effective cost of their programs.

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I. INTRODUCTION

I. INTRODUCTION

This report presents information to help states include a tire inflation check in their existing and planned emissions, safety and combined safety and emissions inspection programs. It has been estimated that as much as 515 million gallons of gasoline are wasted in the United States each year due to improper tire inflation. Tire inflation if added to a state motor vehicle inspection program would help motorists increase vehicle fuel economy and reduce tire wear as well as improve safety. States adding tire inflation to inspection programs would be able to reduce the effective cost of their programs.

BACKGROUND AND SUMMARY

Numerous surveys of the tire pressure of vehicles-in-use have shown that many vehicles are being operated with underinflated tires. It is estimated that if a tire pressure inflation program were implemented in State motor vehicle inspection programs a .36 to 2.2 percent fuel economy benefit for the inspected fleet could be achieved depending on the type of inflation program implemented (see Table 1). As indicated in Table 1, tire inflation would save each vehicle owner between $3.59 and $13.94 in fuel costs per year. Additionally, correct inflation would increase tire life, resulting in an additional savings of $1.23 to $4.54 per year, as well as improve vehicle safety. If the benefits of improved consumer maintenance practices are considered, a tire inflation program could save motorists as much as $28.72 per year.

An examination of available options for implementing a tire inflation check in existing and planned centralized and decentrialized inspection programs indicates that (1) the cost per vehicle of adding a tire inflation check would be about 70 cents, and (2) the test could be added relatively easily. Thus the inclusion of a tire inflation check in State vehicle inspection programs is both beneficial and cost effective from the standpoint of the motorist and State. The net savings for the motorist (fuel economy and treadware savings minus additional test cost) could exceed the total test fee of most inspection programs ($5 to $10).

TABLE 1. Summary of Program Benefits by Inflation Strategy

STRATEGY	INFLATE TO MANUFACTURER'S RECOMMENDATIONS*		INFLATE TO 3 PSI ABOVE MANUFACTURER'S RECOMMENDATIONS*		INFLATE TO MAXIMUM SIDEWALL PRESSURE*	
	Percent	Savings**	Percent	Savings	Percent	Savings
FLEET FUEL ECONOMY BENEFIT						
. Due directly to tire inflation program	.36%	$3.59	.86%	$8.47	1.42%	$13.94
. Due to program and improved consumer maintenance	.82%	$8.17	1.55%	$15.24	2.24%	$21.81
FLEET TREADWEAR BENEFIT						
. Due directly to tire inflation program	1.87%	$1.23	4.42%	$2.82	7.31%	$4.54
. Due to program and improved consumer tire maintenance	4.25%	$2.72	7.99%	$4.94	11.56%	$6.91
TOTAL SAVINGS						
. Due directly to tire inflation program		$4.82		$11.29		$18.48
. Due to program and improved consumer tire maintenance		$10.89		$20.18		$28.72

* Adjusted for temperature.
** Expressed in terms of dollars per vehicle per year.

REPORT METHODOLOGY AND ORGANIZATION

This report is based on (1) a review of existing information on the effects of tire pressure on fuel economy, treadware and safety, (2) discussions with numerous government and industry representatives knowledgeable about tire inflation, and (3) data on the characteristics and capabilities of existing and planned inspection programs resident in Booz, Allen's files.

The report is organized into five chapters and two appendices. Information on the fuel economy and treadware benefits of tire inflation is presented in Chapter II, and information on safety is presented in Chapter III.

Chapter IV discusses the methods of measuring tire inflation in both centralized and decentralized inspection programs. Topics addressed include alternative inflation strategies, equipment and manpower requirements and cost per vehicle.

Since most inspection programs require inspection only once a year, encouragement of vehicle owners to continue to monitor tire pressure throughout the year is important. Thus, means of maintaining tire pressure after inspection were investigated, and the results are presented in Chapter V.

Appendix A contains the methodology employed to calculate the fuel economy and treadware benefits presented in Chapter II, and Appendix B contains a step by step methodology to aid program planners determine the potential cost impact of adding a tire inflation check to their programs.

II. FUEL ECONOMY AND TREADWEAR BENEFITS OF TIRE INFLATION

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This chapter examines the fuel economy and treadwear benefits of proper tire inflation. It is divided into the following sections:

- Current State of the Light Duty Vehicle Fleet Regarding Tire Inflation
- Effect of Tire Pressure on Fuel Economy
- Effect of Tire Pressure on Treadwear.

Information presented in this chapter shows that the total savings per motorist per year due to a tire inflation program will range from $4.82 to $28.72. The beneift due to improved fuel economy is from $3.59 to $21.81 and the benefit due to reduced tire treadwear is from $1.23 to $6.91.

CURRENT STATE OF THE LIGHT DUTY VEHICLE FLEET REGARDING TIRE INFLATION

Several studies have been made over the past few years on the tire pressures of motor vehicles. In general, these studies have indicated that tires on vehicles in the light duty vehicle fleet are underinflated relative to manufacturers' recommendations. Most notable among the studies that were conducted are those by Viergutz et. al. and the U.S. Environmental Protection Agency (EPA). As will be described below, these two studies indicate that depending on the type of tire and climatic conditions, tires average 0.8 to 3.3 psi underinflated, with an overall average underinflation of about 2.0 psi.

Viergutz Study

The Viergutz et al[1] study was based on pressure measurements from a sample of 2400 vehicles parked in the Chicago metropolitan area over a summer and winter period. Vehicles were immobile for at least three hours before any pressure measurements were made. The results of that sample for 15-inch diameter size H and up radial tires on domestic automobiles in winter are shown in Figure 1.

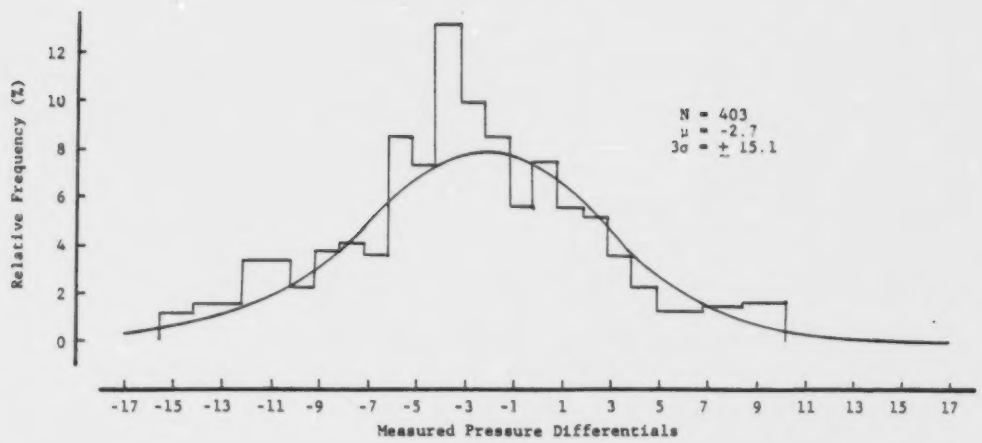

FIGURE 1. Pressure Differential from Manufacturers' Recommendation, Histogram and Estimated Normal Distribution: Radial Tires, 15-inch Diameter, Size H and Up, Domestic Autos, Winter. (Reference 1)

As shown by the figure, the histogram is quite peaked near the mean, and the results indicate an average underinflation of approximately 2.7 pounds per square inch (psi). These results are typical of that found by Viergutz. For all tires measured in the sample, the summer average underinflation was approximately 0.8 psi and the winter average underinflation was approximately 2.5 psi.

U.S. EPA Study

The EPA[6] study was based on a representative sample of vehicle make/models in six different cities: Los Angeles, Houston, Phoenix, St. Louis, Denver and Washington, D.C. Tests were all made at a uniform cold temperature of 76°F and corrected to reflect the mean outside temperature for the month and location of the test.

Table 2 shows the results of the survey. Overall, the average pressure was 2.0 psi less than manufacturers' recommendations. About 63 percent of all tires were underinflated, and of these, the average under-inflation was 4.5 psi.

TABLE 2. Results of EPA Survey

	Front	Rear	Overall
Mean Recommended Pressure, psi	25.9	27.3	26.6
Mean Measured Pressure, psi	24.6	24.5	24.6
Mean Difference, psi	1.3	2.8	2.0
Mean Pressure Difference of Underinflated Tires, psi	4.1	4.9	4.5
Percent Underinflated	56.6	68.4	62.5

Source: References 6 and 12.

The EPA results agree quite well with the Viergutz study and with the general results of other investigators. All subsequent calculations and results presented in this report are based on use of the EPA data. The EPA data was selected for use because it is more representative of vehicles throughout the U.S.

EFFECT OF TIRE PRESSURE ON FUEL ECONOMY

Considerable data have indicated that higher inflation pressure significantly reduces tire rolling resistance and the energy dissipated in a vehicle's tires, leading to an overall improvement in a vehicle's fuel economy. Presented below are the results of studies on this subject plus a discussion of the potential fuel economy benefit of incorporating a tire inflation check in a State vehicle inspection program.

Fuel Economy Versus Rolling Resistance

The exact amount of rolling resistance improvement to be realized from proper tire inflation is a function of the amount of inflation change and the type of tires on

the vehicle. Figure 2 shows the relationship between tire pressure and tire rolling resistance* of a vehicle at 50 mph for different types of tires.

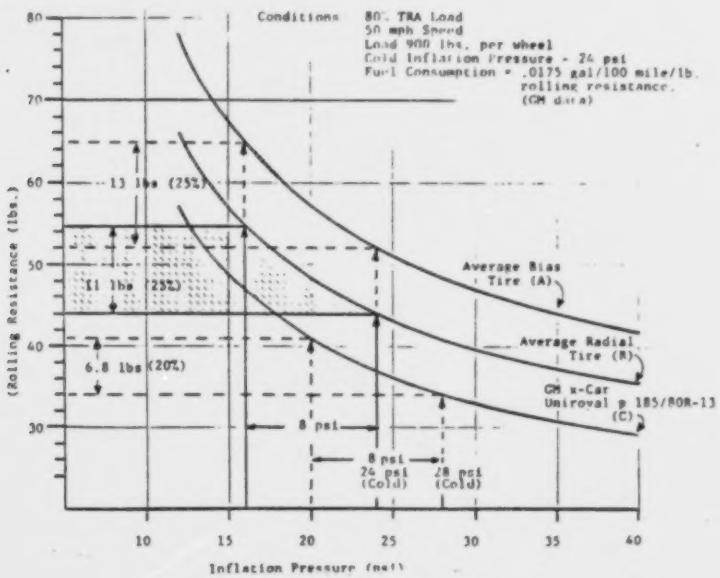

FIGURE 2. Rolling Resistance Versus Inflation Pressure For a 4-Wheel Passenger Vehicle (Reference 2)

The effect of tire rolling resistance on vehicle fuel consumption depends on the particular driving cycles used, average speed of the vehicle, and specific vehicle characteristics. As a general rule, however, the percent change in fuel economy is approximately one-fifth the percent change in rolling resistance. Thus, a 10 percent reduction in rolling resistance would be expected to result in a 2 percent improvement in fuel economy.[4,5] Specific studies relating a change in tire pressure to the change in fuel economy of specific vehicles are discussed in the next section.

Fuel Economy Versus Tire Pressure

Table 3 summarizes the results of three studies which quantified the impacts on fuel consumption of a change in tire pressure. As shown, the results are dependent upon

---

* Rolling resistance is the force required to keep the tire turning at constant speed.

TABLE 3. Effects of Tire Pressure on Fuel Economy

Researcher	Effect on Fuel Economy*	Study Parameters
Grugett et. al.[6]	.33% per psi	Radial Tires, 1979 Chevy Novas, Composite Urban-Highway Driving Cycle
Goodyear[7,8]	.30% per psi	Radial Tires, Full Size Sedan, 45 mph Constant Driving Cycle
	.75% per psi	Bias Tires, Full Size Sedan, 45 mph Constant Driving Cycle
Taylor[9]	.38% per psi	Radial Tires, GM X-Cars, Combination City-Highway Driving Cycle
	.5% per psi	Radial Tires, GM X-Cars, 30 mph Constant Driving Cycle

*Percent Improvement per psi

the type of tire, specific vehicle characteristics and driving cycle. Measurements made on 1979 Chevrolets by Grugett et al[6] indicated a 0.33 percent change in fuel consumption for each psi pressure change for radial tires over a composite urban-highway driving cycle. Goodyear made direct fuel economy measurements of a full size sedan travelling at 45 mph and found a 0.30 percent change in fuel consumption for each psi for radial tires and a 0.75 percent change in fuel consumption for each psi for bias tires.[7,8] Finally, data presented by Taylor on GM X-cars equipped with low rolling loss radial tires indicated that over the 20 to 28 psi range, about a .38 percent change in fuel economy per psi occurs with the combination city-highway driving cycle and about a .5 percent change in fuel economy per psi occurs for a constant 30 mph driving cycle.[9]

In calculating fuel economy benefits for this study, a fuel economy benefit of 0.33 percent per psi was used. This value represents the benefit associated with a

typical vehicle with radial tires driving over an urban-highway driving cycle. This value was selected because it is consistant in general with all studies. Radial tires were assumed because they are becoming the predominant tire on vehicles-in-use.

Potential Fuel Economy Benefits of Incorporating Tire Inflation in a State Vehicle Inspection Program

Assuming an average underinflation of 2.0 psi and an average effect on fuel economy of 0.33 percent per psi, and given that the light duty vehicle fleet consumes 78 billion gallons of gasoline per year[35] one can arque that approximately 515 million gallons of gasoline per year are needlessly consumed due to improper tire inflation.

The fuel economy benefits associated with a specific state tire inflation program depend on the pressure level tires are inflated to during the pressure check. Fuel economy benefits are presented in this section for three different inflation strategies:

- Inflating all tires to manufacturers' recommendations, with temperature adjustment
- Inflating tires to 3 psi above manufacturers' recommendations, with temperature adjustment
- Inflating all tires to the maximum pressure indicated on the tire sidewall, with temperature adjustment.

Chapter IV further defines and addresses the advantages and disadvantages of each inflation strategy. Details of calculations are presented in Appendix A.

A summary of the potential fuel economy benefits by inflation strategy are presented in Table 4. Two sets of results are presented for each inflation strategy:

- The top row presents the benefits associated with inflation during the vehicle inspection.
- The bottom row shows additional benefits that could be achieved if motorists improved their tire maintenance practices as a result of consumer information provided as part of the inflation program (see Chapter V).

The table indicates that a motorist could save $3.59 to $21.81 per year depending upon the inflation strategy and the amount of benefit due to improved tire maintenance.

TABLE 4
Summary of Fuel Economy Benefits by
Inflation Strategy

STRATEGY	INFLATE TO MANUFACTURERS' RECOMMENDATIONS*	INFLATE TO 3 PSI ABOVE MANUFACTURERS' RECOMMENDATIONS*	INFLATE TO MAXIMUM SIDEWALL PRESSURE*
Savings without a consumer information benefit	$3.59	$8.47	$13.94
Savings including a consumer information benefit	$8.17	$15.24	$21.81

* With temperature adjustment

The fuel economy results shown in Table 4 indicate that significant savings could be achieved with an inflation program. An inflation strategy using pressures greater than those recommended by the manufacturer provides considerably more benefit than one using manufacturers' recommendations. In addition, a large benefit can be achieved through an effective consumer information program. Operational and safety implications of the different inflation strategies are discussed in Chapters III and IV.

EFFECT OF TIRE PRESSURE ON TREADWEAR

Fewer studies have been made of the effects of tire pressure on treadwear than on the effects of tire pressure on fuel economy. Nonetheless, sufficient evidence exists to indicate a benefit of proper tire inflation on tread life. Presented below are the results of a recent study conducted by B. F. Goodrich on the relationship between tire pressure and treadwear plus a discussion of the potential treadwear benefits of incorporating a tire inflation check in a state vehicle inspection program.

Relationship Between Tire Pressure and Treadwear

Recently, a series of wearout projections were made by researchers at B. F. Goodrich Company based on tire wearout measurements taken on vehicles with different types of tires running on a test track at different pressures. The results are shown in Figures 3 and 4.

- Figure 3 indicates that the wear of all three tire constructions improves with higher inflation pressures, leveling off at 32 psi.

- Figure 4 indicates that pressure changes of only a few psi change the shoulder/crown wear ratio* of bias and bias-belted tires with, according to the Goodrich report, unacceptable malwear (decreased tire life due to uneven wear at the pressure extremes of 16 and 40 psi. Pressure changes have little effect on radial tire shoulder/crown wear ratio.

Potential Treadware Benefits of Incorporating a Tire Inflation Check in a State Vehicle Inspection Program

The Goodrich data shows approximately 1.7 percent change in tire life for each 1 psi pressure change for radials and a 2.4 percent change in tire life for each 1 psi pressure change for bias tires. However, the bias tires also have a significant change in shoulder-crown wear and may thus be more critically affected by tire pressure than indicated by the average-groove data.

Using the result of radials and assuming an average underinflation of 2.0 psi with 120,000,000 cars on the road and an average tire life of three years, over 5,000,000 extra tires must be purchased each year due to low tire pressure. According to NHTSA[11], 8 gallons of oil are needed to build a passenger car tire. Thus more than 40,000,000 gallons of oil per year may be wasted due to the low tire pressure effect on treadwear.

Appendix A presents some calculations of the reduced tire wear benefits that could be achieved if a tire inflation check were added to a state vehicle inspection program. The results are presented in Table 5. Tire life could be extended 2 to 10 percent (1,000 to 5,000 miles),

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* This is the ratio of the wear on the outside of the tire to wear in the center of the tire.

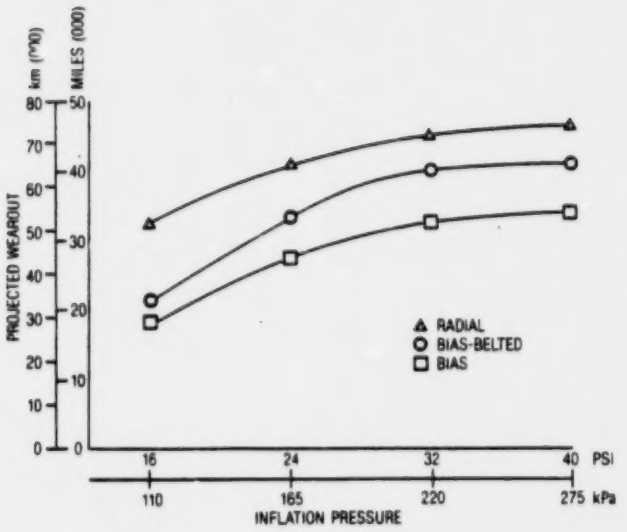
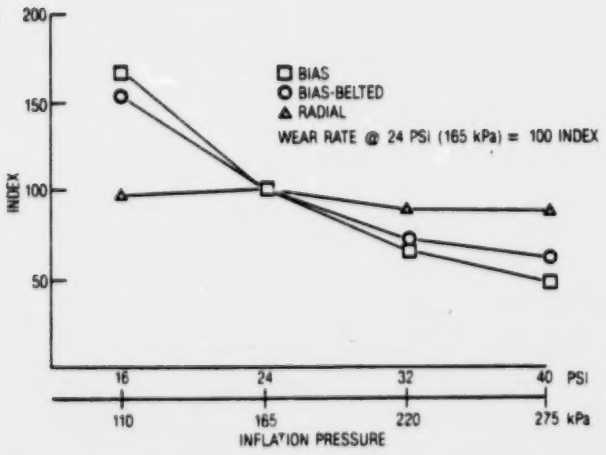


FIGURE 3. Projected Treadwear Versus Inflation Pressure: Average of All Grooves, 85% of T&RA Design Load (Reference 13)



Note: Eacn Tire Type is Given the Value of 100 at 24 psi

FIGURE 4. Shoulder-Crown Wear Ratio Versus Inflation Pressure

and each motorist could save $1.23 to $6.91 per year depending on the inflation strategy. If this amount is added to the fuel economy savings, total savings per motorist per year due to tire inflation in an inspection program would range from $4.82 to $28.72.

TABLE 5
Summary of Treadwear Benefits by Inflation Strategy

Strategy	Inflate to Manufacturers' Recommendations*	Inflate to 3 psi above Manufacturers' Recommendations*	Inflate to Maximum Sidewall Pressure*
Savings without a consumer information benefit	$1.23	$2.82	$4.54
Savings including a consumer information benefit	$2.72	$4.94	$6.91

* With temperature correction.

III. SAFETY BENEFITS ASSOCIATED WITH TIRE INFLATION

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In addition to fuel economy and treadware, there are also a number of safety considerations associated with proper tire inflation. This chapter examines the effects of tire pressure on vehicle safety, specifically addressing the following issues:

- The relationship between low tire pressure and vehicle accidents.
- The effects of tire pressure on vehicle handling, tire failure and front suspension system wear.

The information provided in this chapter indicates that:

- There are definite safety benefits in adjusting vehicles with low tire pressure to the pressures recommended by the manufacturer. The benefits result from reduced chance of tire failure and improved vehicle handling.
- The same safety benefits resulting from inflating low tire pressures to manufacturer recommended pressures apply to inflating vehicles with low tire pressure to pressures 2 to 3 psi over vehicle specifications, since the evidence does not indicate significant handling effects with pressure changes in the 2 to 3 psi range.
- Changes in handling are of concern as pressures are increased further over vehicle specifications. However, some fleets have found that successful vehicle operation is possible with tires inflated to the maximum pressure indicated on the tire sidewall. Any changes in handling are not considered problems by drivers. Pressures should not be increased beyond the maximum sidewall pressure to prevent any chance of tire failure.
- Maintenance of manufacturer's recommended front-to-rear pressure differences will in general lessen any handling effect caused by inflating tires to pressures higher than those recommended

by the manufacturer. Eliminating front to rear pressure differentials of 6 psi or more is likely to result in a noticeable change in vehicle handling.

- There is some indication that pressures 4 to 6 psi higher than those recommended by the vehicle manufacturers may cause excessive loads on the suspension system of older vehicles.

- Auto manufacturers' recommendations for tire pressure are based upon research which balances ride, handling, fuel economy and other vehicle-related factors for a specific auto model. Since these represent industry standards that can be used in product liability litigation, manufacturers may hesitate to recommend overinflation to improve one factor, such as fuel economy.

RELATIONSHIP BETWEEN LOW TIRE PRESSURE AND VEHICLE ACCIDENTS

The National Highway Traffic Safety Administration has estimated that low tire pressure is responsible each year for 260,000 accidents, 720 deaths and 28,000 disabling injuries.[21] These estimates are based on a study conducted by Indiana University in which an investigation of hundreds of accidents identified low tire pressure as being a probable or certain cause of accidents in .5 to 2.3 percent of the observed cases. A brief description of this study and another study conducted by the Highway Safety Research Institute (HSRI) is presented below. While the HSRI study does not confirm NHTSA's estimate, it does nonetheless suggest that tire maintenance practices are poor and that improper tire matching and maintenance practice are likely accident causation factors in crashes involving wet or slippery roads.

Indiana University Study

A study in 1973 by Indiana University attempted to ascertain the relative roles played by human, environmental and vehicular deficiencies in causing and increasing the severity of automobile accidents.[20] Information was gathered through on-site examination of hundreds of accidents and an in-depth analysis of the cause of many of these accidents was also undertaken. No instances of blow-out or sudden tire failure were found during the investigation. In addition, in less than .2 percent of the accident cases did any investigating team attribute low tire pressure as a certain cause of the accident. Low

tire pressure was sited as a probable or certain cause of accidents in .5 to 2.3 percent of the observed cases, depending on the investigation team and accident sample.

Highway Safety Research Institute Study

The Highway Safety Research Institute performed an analysis of tire data collected on 518 vehicles involved in accidents between September 1, 1975 and September 1, 1977.[19] The study attempted to determine the frequency of improper inflation and its relationship to accident causation.*

The approach of the study was to compare the tire pressures of randomly selected vehicles from Michigan State Police checklane inspections conducted in the summer of 1976 with the pressures of cars and light trucks involved in accidents. Key findings of the study are as follows:

- No significant difference was found between the overall inflation pressures of the accident and control samples.
- Tire pressure imbalances in the accident sample were significantly greater than those in the control sample.
- Accident vehicles that had the greatest imbalance of tire pressures were those involved in crashes on slippery roads.

The study concluded that tire maintenance practices are generally poor, but there is no evidence to implicate poorly maintained tires as causative factors for accidents on dry roads. However, improper tire matching and maintenance practices appear to be accident-causation factors in crashes involving wet or slippery roads.

TIRE PRESSURE AND VEHICLE HANDLING

The effects of tire pressure on vehicle handling are generally measured in terms of three factors:

- Traction
- Oversteer and Understeer
- Aligning Torque.

* The study also examined the effects of mismatched or worn tires.

Each is discussed below along with an examination of the experience of certain fleets which have increased the tire pressures on their vehicles above manufacturer's recommendations as a means of increasing fuel economy.

Effect of Inflation Pressure on Traction

Tire traction is an important vehicle handling parameter. It is associated with a vehicle's ability to brake and accelerate, and is particularly critical during wet weather. In order to assess the effect of inflation pressure on traction, Goodrich researchers ran wet and dry traction tests at Automotive Proving Grounds in Pecos, Texas. The results are presented in Figure 5. As shown, in every case the data indicates that changes in inflation pressures generally do not adversely affect wet or dry traction.

Effect of Inflation Pressure on Vehicle Understeer and Oversteer

The effects of tire inflation on vehicle "understeer" and "oversteer" have been investigated in several studies.[14,15,16] Understeer and oversteer refer to the radius of the circle made by a turning vehicle compared to the radius of the circle a vehicle would traverse according to the angle of the front wheels (see Figure 6). Thus, if a car turns in a larger circle than one would expect given the turning angle of the front wheels, the vehicle has "understeer." If the circle radius is smaller than the angle of the front wheels would suggest, then the vehicle has "oversteer."

Changes in vehicle understeer or oversteer will change vehicle handling, especially during turns. However, a safe level of understeer or oversteer cannot be defined. Most American cars have significant understeer, and changes in the amount of understeer would normally not be detected by most drivers. For state motor vehicle inspection programs, concerns center around not whether a certain level of understeer is safe, but rather if:

- Changes in understeer as a result of correct tire pressure will improve vehicle handling.
- Changes in understeer due to tire inflation higher than that recommended by the vehicle manufacturer will be sufficient to be noticed by motorists or cause excessive adjustments on the part of motorists.

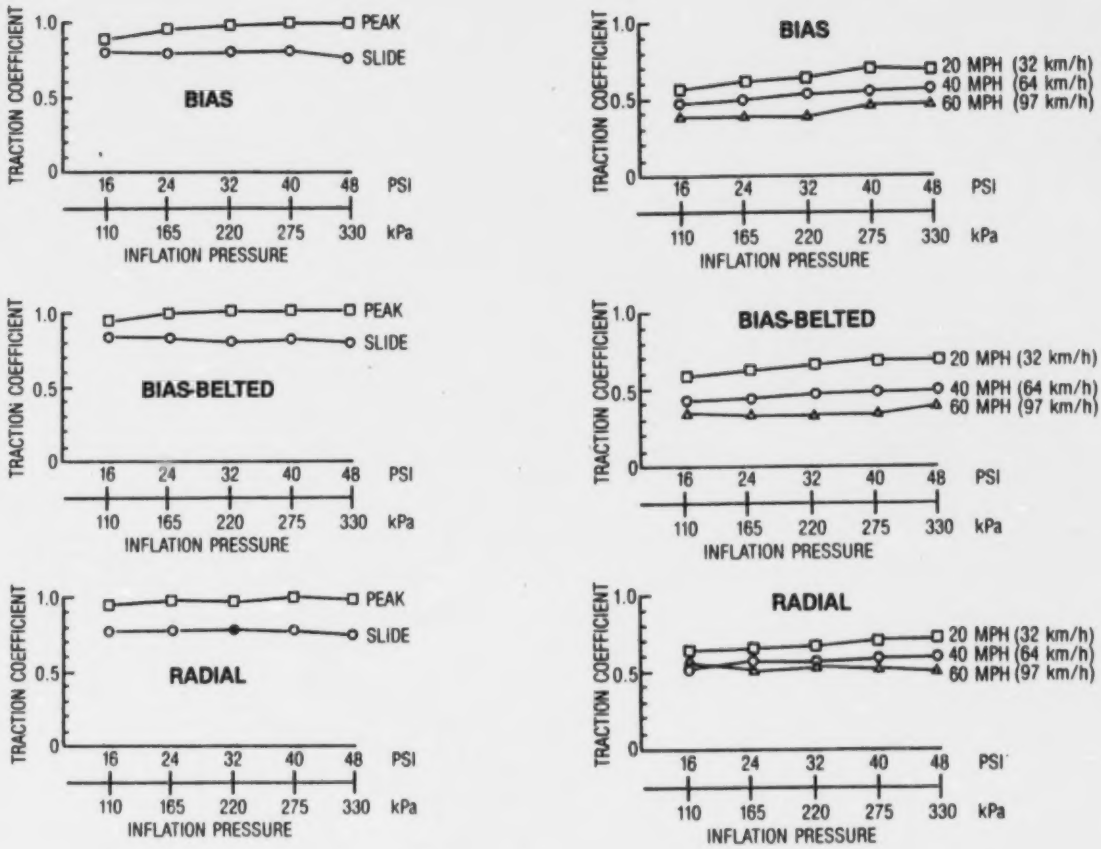

FIGURE 5: Dry Traction (Left) and Wet Peak Traction (Right) Versus Inflation Pressure

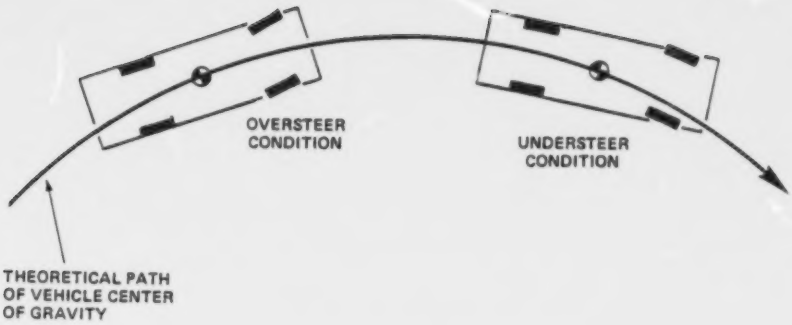

FIGURE 6. Geometry of Understeer and Oversteer

Presented below is a summary of three studies which document the effect of tire inflation pressure on vehicle understeer and oversteer. The first study is by B. F. Goodrich Company. This study relates vehicle steering to a coefficient called the "cornering coefficient." The other two studies are by the Highway Safety Research Institute. Both these studies relate vehicle steering to an understeer/oversteer factor. The important point to note in reading these summaries is that very large changes in understeer can adversely effect vehicle handling.

Goodrich Study

A key vehicle parameter that affects the steering characteristics of a vehicle is the cornering coefficient of the tires. If a cornering coefficient is too high, the vehicle will have less understeer and the steering response may be too quick for the average driver. A cornering coefficient that is too low will result in insufficient steering response.

Figure 7 shows the effect of inflation pressure on cornering coefficient as measured in a study conducted by by B. F. Goodrich Company. The B. F. Goodrich researchers who conducted the study point out that coefficients below those found at 16 psi are unacceptable and coefficients for radials at 40 and 48 psi are above current practice.

Thus, the results of the B.F. Goodrich study imply that tires with very low pressure should realize significantly improved handling if inflated to manufacturers recommendations in an inspection program. In addition, the study also indicates that tires inflated to pressures ranging between 16 and 40 psi (i.e., the entire target pressure range that might be used in an inspection program) have cornering coefficients that are within current industry practice.

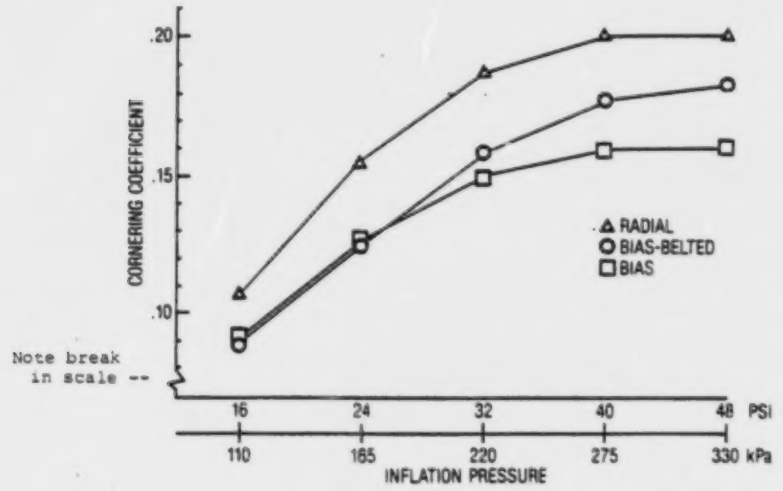

FIGURE 7. Cornering Coefficient Versus Inflation Pressure (100% of Tire and Rim Association Design Load) (Reference 13)

Highway Safety Research Institute Studies

Researchers at the Highway Safety Research Institute investigated the effects of tire pressure on steering on a 1971 Mustang.[36] The understeer/oversteer factor (K) was evaluated experimentally for seven different tire-in-use conditions. The tire conditions and the corresponding test results are given in Table 3. As shown, the base case vehicle has approximately 4.7 degrees per g of understeer. This means that for a typical turn with 0.1g of lateral acceleration,* the front wheels are turned .47 degrees more than expected. (Alternately, a 0.47 degree change in reference steering angle is required to stay on the same radius path if the vehicle speed is increased

* This is the acceleration toward the center of the turn. The effect on an occupant is often termed centrifugal force.

TABLE 3. Tire Pressure and Understeer For a 1971 Mustang

Case	Tire Configuration	K (+ understeer) deg/g	
		Left Turn	Right Turn
1	Original equipment 24 psi all wheels	4.9	4.5
2	Original tires, 24 psi front, 12 psi rear	0.9	0.9
3	Original tires, 24 psi front, 18 psi rear	4.1	3.1
4	Original tires, 18 psi front, 24 psi rear	5.8	7.9
5	Original tires, 12 psi front, 24 psi rear	10.4	10.6
6	Original tires, heavily worn on front, non-worn on rear, 24 psi all tires	2.7	3.5
7	Original tires on the rear, radial tires on the front, 24 psi all tires	1.0	0.9

Source: Reference 36

enough to obtain a 0.1g increase in lateral acceleration). In cases 2 and 5 where there is a full 12 psi differential between the front and rear tires, understeer changes by as much as 5 deg/g. When the pressure change is 6 psi (cases 3 and 4), the understeer change is 1 to 2 deg/g.

It should be noted that in case 3, reduced rear tire pressure of 6 psi causes a decrease in understeer of .8 to 1.4 deg/g whereas in case 4, reduced front tire pressure of 6 psi causes an increase in understeer of 1.1 to 2.4 deg/g. In most cases if both the front and rear tires of a vehicle have their pressure changed by a fixed amount, the overall effect on vehicle understeer will be less than

if only the pressure of tires on one axle were changed.* For this reason, several industry spokesmen recommend the maintenance of front-to-rear tire pressure differentials when increasing overall tire pressure above manufacturers' recommendations so that fuel economy is improved with a minimal effect on vehicle handling.

Calculations presented in another study[37] by the Highway Safety Research Institute give some examples of vehicle factor changes and the contribution to understeer. The study suggests the following for certain tires and vehicle characteristics:

- About 2 deg/g increase in understeer occurs in changing from power steering to manual steering.
- Adding three passengers to the rear seat of a compact car with E78-14 tires can reduce understeer by 1.3 deg/g.
- Holding rear tire pressure within ±6 psi will maintain understeer within ±0.5 deg/g at 1,032 pounds load per wheel while at 1,374 pounds load per wheel the inflation pressure would have to be held within ±3 psi to keep understeer within ±0.5 deg/g.

The Highway Safety Research Institute studies summarized above indicate that if the pressure of both tires on a single axle is held within ±3 psi of vehicle manufacturers' specifications, the change in understeer will generally be under 0.5 deg/g. This change is quite small; it is about the same as the difference in understeer between a left turn and a right turn in the test vehicle of Table 3 and is substantially less than the change in understeer that occurs in some vehicles when adding three passengers to the rear seat. A pressure change for both tires on a single axle of ±6 psi is likely to cause an understeer change of 0.5 to 1.5 deg/g depending on the vehicle. This much change could start to have a noticeable effect on vehicle operation. Industry spokesmen have indicated that if the front to rear pressure differential recommended by manufacturers is maintained as tires are inflated beyond manufacturers' specifications, then any effect on vehicle handling will be reduced. Based on these findings, it can be concluded that:

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* In one mathematical model of understeer, total vehicle understeer is due to an understeer factor attributed to the front wheels minus an understeer factor attributed to the rear wheels.

- Inflating very low tires in a vehicle inspection program will likely improve vehicle handling.

- Inflating tires 2 to 3 psi above manufacturers recommendations will have very little effect on vehicle handling compared to a vehicle with tires inflated to manufacturer's specifications.

- The effect of pressure increases above manufacturers' recommendations will be minimized if front-to-rear pressure differentials are maintained. A pressure change of 6 psi or more on both tires on only one axle will likely start to have a noticeable effect on vehicle operation.

Effect of Inflation Pressure on Aligning Torque

Besides changing the understeer on a car, tire pressure changes will also impact the aligning torque of the front wheels. Aligning torque refers to the tendency of front tires to straighten themselves during a turn. A reduction in aligning torque will result in a reduction in steering feel. As shown in Figure 8, aligning torque decreases with increasing pressure.[38] Increasing pressure will reduce steering feel and also adversely affect a vehicle's natural tendancy to track in a straight line.

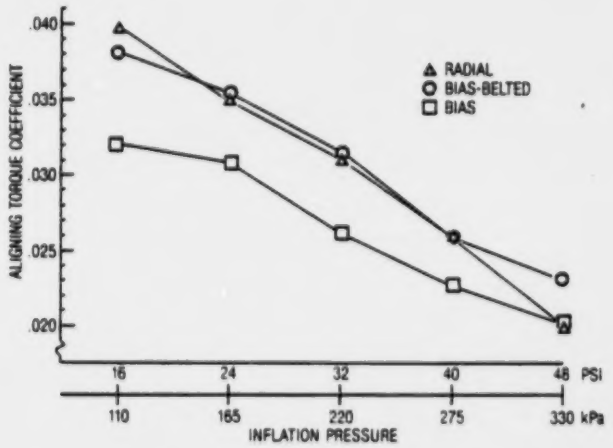

FIGURE 8. Aligning torque versus inflation pressure (100% of Tire and Rim Association design load; 1° slip angle) (Reference 13)

According to Goodrich researchers[38], the loss of aligning torque is further impacted by the gain in cornering coefficient as pressure is increased. Because of the increased cornering power, less steer angle is required and this further reduces the steering feel when pressure is increased.

Given the above findings, it is difficult to assess the effect of a change in aligning torque as a result of a specified pressure change due to the interaction between aligning torque and cornering on steering feel. Nevertheless, the small pressure changes discussed in the last section (2 to 3 psi) appear to be sufficiently small that no problem due to a change in steering feel will be experienced by motorists.

Experience of Certain Fleets Using Elevated Tire Pressures

To increase fuel economy, several fleets throughout the country have increased the tire pressure of vehicles in their fleets to the maximum pressure indicated on the tire sidewall. This pressure is determined according to the resistance of the tire to bruising and other types of failure, whereas the vehicle manufacturers' recommended pressures are generally set lower to improve the ride of the vehicle.

Two organizations that have used elevated tire pressures in their fleets for many years to improve fuel economy are the Tennessee Valley Authority and the U.S. Postal Service. Neither of these fleets have reported any handling problems with the vehicles changed in this way.* Any changes in vehicle handling that may have resulted from the pressure changes are not considered a problem by vehicle drivers.

Summary of Effects of Tire Inflation on Vehicle Handling

The above evidence indicates the following:

- Inflation of a vehicles' tires when they are seriously underinflated is likely to improve the steering response of the vehicle, and this may be considered one benefit of a tire inflation program.

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* The Postal Service track tests its vehicles before specifying a pressure setting to insure optimum economy and vehicle handling.

- Tires which are slightly underinflated or overinflated relative to the vehicle manufacturers recommendations (i.e., within 2 or 3 psi) have only a minimal effect on steering response.

- At some point, which may vary from car to car, overinflated tires (relative to the vehicle manufacturers recommended specification) may cause changes in vehicle handling which will be unacceptable to some motorists. However, evidence from certain fleets, such as the TVA, indicates that inflating tires to the maximum pressure indicated on the sidewall will not cause unacceptable handling changes.

- The maintenance of front to rear tire pressure differentials will lessen the effect on vehicle handling of tires inflated to pressures above those recommended by manufacturers. A 6 psi or more pressure change on both tires on one axle will likely start to have a noticeable effect on vehicle operation.

Thus, in summary, tire inflation programs that are set to inflate tires above vehicle manufacturers recommendations will generally not cause unacceptable vehicle handling effects. Tire and vehicle manufacturers have, however, shown restraint in recommending elevated tire pressures, especially more than 3 psi over manufacturers' recommendations on each axle. Auto manufacturers' recommendations for tire pressure are based upon research which balances ride, handling, fuel economy and other vehicle-related factors for a specific auto model. These represent industry standards that can be used in product liability litigation--hence, manufacturers may hesitate to recommend overinflation to improve one factor, such as fuel economy.

TIRE PRESSURE AND TIRE FAILURE

In addition to affecting vehicle handling, the pressure of a tire also has an effect on its resistance to failure. A grossly underinflated tire can lead to tire failure from excessive flexing and tire heat buildup[18], while an overinflated tire is more vulnerable to impact damage and weakening of the tire body. The effects of elevated tire pressure on tire failure are best documented in a recent study conducted by B. F. Goodrich Company.

Researchers at B. F. Goodrich Company recently conducted dynamic bruise tests of tires at different pressures.[17] The results of these test are shown in Figure 9. The results are based on tests where researchers measured the height at which a nub at a 45 degree angle would puncture a fully loaded tire at 60 miles per hour. As shown in the figure, tires of all three types of construction are more easily bruised at higher pressures, although radials and bias-belted tires have a greater bruise resistance than the bias tires. Thus, from the point of view of a testing program, care should be taken that the maximum pressures indicated on a tire's sidewall are not exceeded when the tire is cold (ambient temperature).

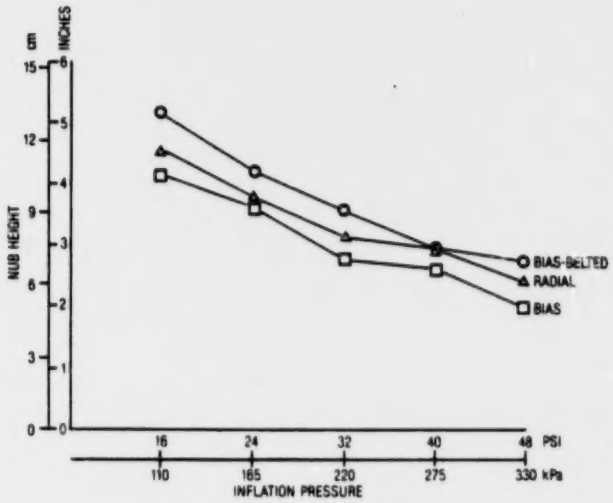

FIGURE 9. Dynamic Bruise Protrusion Height Versus Inflation Pressure (100% of T&RA Design Load; 60 m.p.h.) (Reference 13)

TIRE PRESSURE EFFECTS ON THE VEHICLE SUSPENSION SYSTEM

Only a limited amount of research has been done on the effects of elevated tire pressures on the structural parts of the automobile, especially the suspension system. According to GM engineers, increasing tire pressure 4 to 6 psi can substantially increase loads on tie rods, steering gears, ball joints and parts of the body and frame.

This may lead to problems in older vehicles that were not designed for these loads, such as premature wear of parts. The limited research that has been done suggests that if pressures are increased more than six psi above manufacturers' specifications, motorists should be advised to be sure to include underbody inspection as part of the regular preventive maintenance for their vehicle.

IV. INCORPORATING A TIRE INFLATION CHECK IN EXISTING AND PLANNED INSPECTION PROGRAMS

IV. INCORPORATING A TIRE INFLATION CHECK IN EXISTING AND PLANNED INSPECTION PROGRAMS

The previous chapters have indicated that proper tire inflation is beneficial both from the standpoint of the State as well as the motorist. The purpose of this chapter is to (1) examine alternative tire inflation strategies, and (2) examine the impacts of incorporating a tire inflation check in existing and planned emissions, safety, and combined safety and emissions inspection programs. The impacts discussed include equipment requirements, manpower requirements and costs.

ALTERNATIVE INFLATION STRATEGIES

A key policy to be decided when adding an inflation check to a State motor vehicle inspection program is the appropriate pressure level for tire inflation. Most vehicles manufactured in the last ten years have had recommended inflation pressures between 22 psi and 32 psi. Examples of exceptions to this are indicated in Table 6.[29] Note that to improve fuel economy manufacturers have increased recommended pressures significantly for recent car models. Many vehicles also have a difference in pressure specified between the front and rear tires. This differential is usually under 4 psi, but for some models, especially pre-1978 Volkswagons, Corvettes and station wagons the difference can be much higher.

This section describes three different methods or strategies of inflating tires in a state motor vehicle inspection program. The three strategies are:

- Inflating all tires to the manufacturer's recommended pressure, adjusted for tire temperature.
- Inflating all tires to 3 psi above the manufacturer's recommended pressure, adjusted for tire temperature, with the provision that no tire be inflated above the maximum pressure on the tire sidewall when adjusted for temperature.
- Inflate all tires to the maximum sidewall pressure, usually 32 psi, adjusted for temperature.

Although other specific inflation strategies may be chosen by certain states, these three strategies represent the range of choices available to states. The benefits

TABLE 6. Examples of Vehicles With Manufacturers Recommended Pressure Less Than 22 PSI or More Than 32 PSI on Models Manufactured Since 1972

Vehicle	Pressure	
	Front	Rear
Volkswagen Beetle, Wagon, Convertible, Karmann Ghia 1953-1977	17-18	26-29
Porsche 8-928 1978-1981	36	36
Peugeot 72-79 Station Wagon	23	40
Mercedes 4-190, 1960-68	21	27
Pontiac, LeMans 6 cylinder 1978-1979	28	35
Corvette 1973-1977	20	26
Matador Station Wagons 1972-1978	20	28
1981: Chevrolet Malibu	35	35
Oldsmobile Cutlass	35	35
Pontiac, LeMans	35	35
Plymouth TC3, Horizon, Reliant	35	35
Buick Century	35	35
Ford Escort	35	35
Ford Mustang	35	35

Source: Reference 29

associated with each of these strategies are shown in Table 7. Details are provided in Appendix A. As can be seen in the table, considerable extra benefits are gained in Strategies 2 and 3 which involve pressures greater than the manufacturers' recommended specifications. The operational requirements and safety considerations associated with each of these inflation strategies are discussed below.

TABLE 7. Summary of Benefits by Inflation Strategy (Dollars Per Vehicle)

Benefit	INFLATION STRATEGY: Inflate to Vehicle Manufacturers' Recommendations	Inflate to 3 psi Above Manufacturers' Recommendations	Inflate to Maximum Sidewall Pressure
Fuel Economy Savings Due Directly to Program	$3.59	$8.47	$13.94
Treadware Savings Due Directly Savings	1.23	2.82	4.54
Fuel Economy and Treadware Savings Due to Improved Consumer Maintenance	6.07	8.89	10.24

Strategy 1: Inflate All Tires to the Manufacturer's Recommended Pressures

For this strategy, an inspector in an inspection/maintenance program would determine the manufacturers' recommended pressures of each vehicle and inflate the tires to the specified pressures. The auto manufacturers' recommended pressures are easily accessible on most vehicles manufactured since the late 1960's and are most often found on the door pillar of the driver's side. Reading the label will normally take about 10 seconds. Pressures for venicles without information placards on the vehicles can readily be obtained from tire booklets, such as the "Tire Guide."[29]

Once the inspector has determined the manufacturer's recommended tire pressures, the next step is to inflate the tires. Even with the correct vehicle manufacturer's recommended pressures known, however, it is still not clear what pressure should be set for each tire since the tire temperature is not known. According to the Rubber Manufacturers Association a typical tire can increase in pressure up to 4 psi when hot (as when driven for a half

hour at highway speeds). Manufacturers' recommended pressures are specifically set for a cold tire, one driven less than a mile. At a State inspection facility, some tires will be cold and many will be hot. The Tire Industry Safety Council recommends that if a tire is inflated when hot, the recommended pressure should be increased 3 to 4 psi and then rechecked when the tire is cool. This would be a reasonable strategy for a State inspection program given a procedure for determining a "hot" tire. A simple and commonly employed method of determining a "hot" tire is by placing one's hand on the sidewall of the tire. A "hot" tire will be noticeably warm to the touch. While somewhat crude, this procedure is simple and can be easily incorporated in a state inspection program. It may be possible to develop a method to measure tire sidewall temperature to more accurately determine correct tire pressure. However, no such procedure has apparently been developed to date and the operating inconvenience seems unwarranted given the small potential error in setting pressure by the more approximate means described above.

Inflation strategy 1 for a State inspection program can be summarized as follows:

- Read the manufacturers recommended pressure off the information placard on the vehicle.
- Inflate underinflated tires to the manufacturer's recommended pressure. For "hot" tires increase the pressure by 3 to 4 psi.
- Inform the motorist of the importance and responsibility of maintaining proper tire pressure (See Chapter V).

Inflation strategy 1 provides the least benefits of the three strategies outlined in this section. It also represents the most conservative approach to tire inflation since the manufacturers recommended inflation pressures are strictly followed.

Strategy 2: Inflate All Tires to 3 psi Above the Manufacturers' Recommended Pressures

For strategy 2, tires are inflated to 3 psi above the vehicle manufacturer's specifications. As described in Chapter II, increased tire pressure beyond that recommended by the vehicle manufacturer will continue to improve fuel economy and treadwear. The Tire Industry Safety Council Recommends: "For increased gas mileage and optimum tire performance add 2 to 3 psi more than

indicated on the information placard. However, never exceed the maximum inflation pressure as indicated on the tire sidewall." Further, as discussed in Chapter II, a pressure change of 2 to 3 psi will have only a minimal impact on vehicle handling and safety, especially since the front to rear pressure differential is maintained. The additional savings for the motorist are significant, as indicated in Table 7. As with strategy 1, an additional 4 psi should be added to the tires if they are hot.

Strategy 2 can be summarized as follows:

- Read the manufacturer's recommended pressure off the information placard on the vehicle. Note that the front and rear tires have different recommended pressures.
- Add 3 psi to the recommended pressure. Make sure this is not higher than the maximum pressure on the tire sidewall.
- For hot tires add another 3 to 4 psi to all tires.
- Inform the motorist of the importance and responsibility of maintaining proper tire pressure (See Chapter V).

Strategy 3: Inflate All Tires To The Maximum Sidewall Pressure

For strategy 3, all tires are inflated to the maximum pressure indicated on the tire sidewall. This pressure is usually 32 psi although for many newer tires it is 35 psi. By inflating all tires to the maximum tire sidewall pressure vehicle inspectors will not have to identify the manufacturers' recommended pressures. This can save time and also eliminate the inconvenience caused by attempting to identfy the recommended pressure when the information placard is not present or is obscured. However, since only a single pressure is used for a wide variety of vehicles, the pressure set compared to the vehicle manufacturers' recommendations will have a wide range.

Based on the discussion of safety and handling effects of tire pressure in Chapter III, it would be prudent to avoid inflating the tires on certain vehicles with unusual manufacturers' recommended pressure settings. As a general guide, vehicles with 6 or more psi front to rear pressure differentials should not be inflated in the program. This would eliminate such vehicles as station wagons, Corvettes and Volkswagen Beetles. A specific list

of excluded vehicles can be assembled before program start-up by using a source such as the "Tire Guide" referenced at the end of this report.[29] Assembling such a list at the beginning of a program will save time during the inspection process, since the inspector will not have to look up the vehicle manufacturers recommended pressures do identify "exempt" vehicles.

Strategy 3 can be summarized as follows:

- Make sure the vehicle is not on the list of makes to be excluded from the inflation program
- Identify the maximum pressure indicated on the sidewall and inflate all tires to this pressure. If the tire is hot, add 3 to 4 psi.

With strategy 3, there would be little variance in operating procedure from car to car. The benefits of strategy 3 as shown in Table 7 are more than for strategy 2. While this strategy may change the handling characteristics of certain vehicles, experience of fleets such as the TVA indicate that this will be acceptable to most drivers.

EQUIPMENT REQUIREMENTS

Since most decentralized inspection facilities would already have tire inflation equipment the following discussion pertains solely to centralized inspection programs. Two basic pieces of equipment are needed to inflate tires in a centralized inspection program: a compressor and a tire gauge. While the number of gauges per facility would be proportioned to the number of lanes, for an inspection facility with as many as four lanes, only a small air compressor would be required to service all the lanes. Examples of such units with prices are shown in Table 8. A typical air compressor (see Figure 10) requires 4 1/2 feet by 2 1/2 feet of floor space and 3 1/2 to 4 feet of height. The compressors generally provide air at pressures considerably higher than that needed to inflate tires, usually over 100 pounds per square inch. As a result, the compressor could be used for other purposes as well, including powering lifts and tools.

TABLE 8. Tire Inflation Equipment

Type of Equipment	Equipment Description	Typical Manufacturer	Price
Air Compressor	Compressor & Tank	Ingersoll Rand Model 2-253.35	$4200*
	Compressor & Tank	Dresser-Wayne 10 HP Deluxe	$5000*
	Compressor & Tank	Ingersoll Rand 5 HP	$1400*
	Tankless compressor	ECO 108C	$1325
	Self-service compressor	Champion 3/4 HP	$ 350*
Tire Inflator with Integral Pressure Gauge	In-line gauge	Grover Model - 907	$31.00
	Preset tower gauge	ECO 97	$445.00

* Any piping will be extra

In order to inflate tires to the variety of pressures now specified by manufacturers, a means of measuring and adjusting pressure is required. Two methods are feasible. One uses a gauge in-line with the tire pressure hose as shown in Figure 11. When the hose is connected to the tire the gauge reads the tire pressure. The inspector can insert air into the tire by depressing a lever on the gauge and upon releasing the lever the pressure can again be read. In this manner a tire can be quickly and accurately (within 1 pound per square inch) inflated. Alternately a gauge can be purchased such as the one shown in Figure 12 where the pressure is set to a specified amount and the operator merely holds the hose to the tire. Prices for typical gauges are also shown in Table 5.

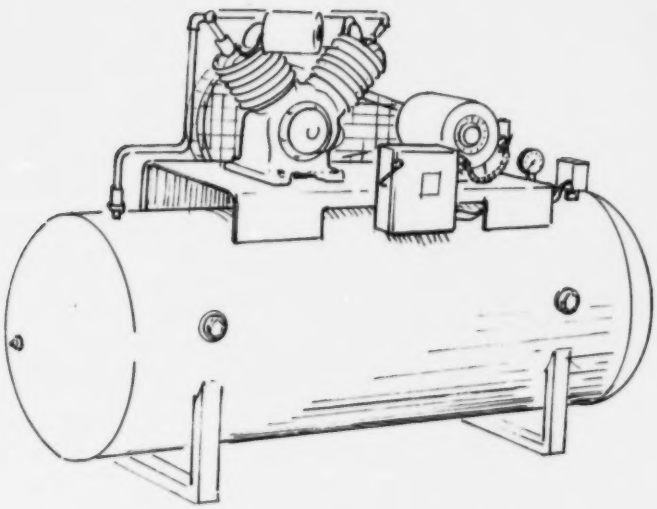

FIGURE 10: A Typical 5 HP Compressor

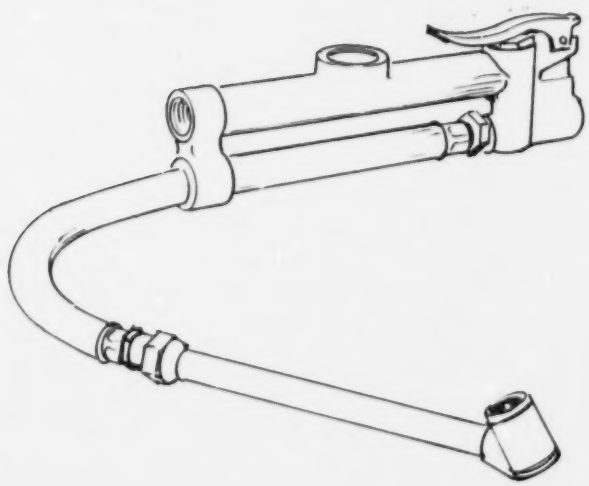

FIGURE 11: An In-Line Gauge

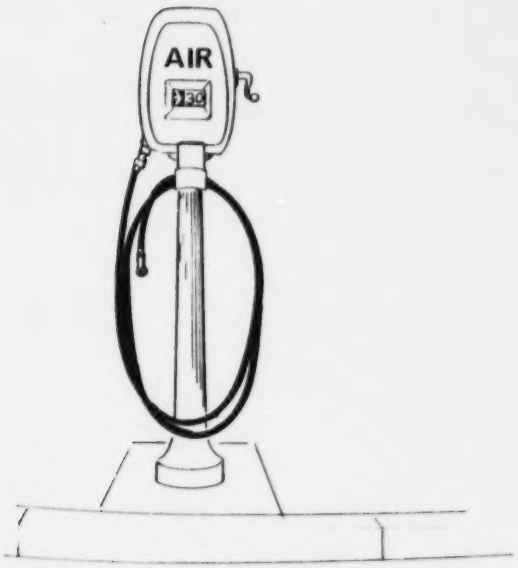

FIGURE 12: An Air Tower With Pre-Set Pressure

Certain other types of inflation equipment have yet to be developed but may be helpful in the future. Operators of centralized programs should discuss these with their contractors or equipment vendors as appropriate to see if they may be feasible. Ideas include:

- A computer library of vehicle tire specifications, indexed by make, model year, etc.
- A method of measuring the pressure automatically with a device that mechanically squeezes the tire sidewalls. Research has been made along these lines, but to date such equipment is not available.
- The incorpration of automatic tire temperature measurement and pressure adjustment in the inflation equipment.
- An improvement to the air tower (Figure 12) that would allow pressure adjustment at the end of the hose and would increase the speed of inflating tires.

MANPOWER REQUIREMENTS AND COST IMPACTS

No existing state inspection program inflates tires as part of the regular inspection process. However, the Keystone Auto Club (AAA) in Philadelphia inflates tires on a regular basis in its diagnostic center. In this center tire inflation is checked while vehicles are in a ground-level station (as opposed to up on a lift). The inspector opens the driver's door and reads the recommended tire pressure on the tire inflation placard. He then uses a hose with an in-line gauge to inflate the tires. As shown in Table 9, the process consistently takes about a minute and forty seconds.

TABLE 9. Approximate Times to Inflate Tires

Procedure	Time
Read pressure on door	10 sec.
Pressurize tire one	20 sec.
Pressurize tire two	20 sec.
Walk around car	10 sec.
Pressurize tire three	20 sec.
Pressurize tire four	20 sec.
TOTAL	1 min. 40 sec.

Source: Time studies made by Booz, Allen and Hamilton at the Keystone Auto Club

Given that the times presented in Table 6 are representative,* the remainder of this section discusses the manpower requirements and cost impacts of incorporating a tire inflation check into existing centralized and decentralized inspection programs. The section is divided into the following parts:

- Checking the Tire Pressure and Inflating the Tires If Necessary in Centralized Inspection Programs.

* The times are for an in-line tire gauge. Use of the tower-type gauge would probably result in longer times if different front and rear tire pressures required resetting the pressure.

- Checking the Tire Pressure and Inflating the Tires If Necessary in Decentralized Inspection Programs.

- Checking Tire Pressure Only in Centralized and Decentralized Inspection Programs.

Checking Tire Pressure and Inflating Tires if Necessary in Centralized Inspection Programs

This section presents four examples of an inflation check incorporated into existing centralized inspection lanes. Each example consists of a schematic diagram showing the existing layout of the lane followed by a discussion of the best location for the inflation check plus the manpower requirements and costs associated with adding the check to the lane. The purpose of these examples is to demonstrate the feasibility of the check and to provide guidance to program planners on the best location and cost impact of the check.

A central criterion used to determine the best location for the inflation check in the examples which follow was that it have minimal impact on the throughput of the lane.* As a general rule, it is only feasible to add equipment and or tests to existing facilities if they have little or no impact on throuhput. For those planners now considering centralized inspection programs, it should be recognized that you now have an opportunity to incorporate a tire inflation check into the program at low cost. Failure to think ahead can result in the need for costly facility expansion at a later date.

Given this criterion, in determining the best location for the inflation check the following general rules were followed:

- Whenever possible personnel were added to keep throughput constant rather than maintaining the existing personnel level and decreasing throughput. In general, it is less expensive, at least in the short term, to handle an increased inspection load by adding personnel than to allow throughput to drop to the point that new facilities are required.

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* Throughput is the number of vehicles that can be processed in one lane or facility over a specific period of time and is commonly expressed in vehicles per lane per hour. A significant drop in a facility's throughput translates into longer hours of operation or the necessity for the construction of new facilities to handle unmet processing requirements.

- Maximum use was always made of the existing inspectors' time. Making use of this time helps to offset the costs of adding inspectors to keep throughput constant.

- When at all possible, the check was added to that station with the greatest amount of slack time. This helps to balance the lane. A well balanced lane is most efficient.

Because it is likely that your program will differ from the examples provided, you should also follow these same rules in determining the best location for the check in your program.

In determining the cost impact of adding the check to the lane, the following was assumed:

- An inspector salary including fringe of $18,000.

- Straight line depreciation of equipment over five years at an annual interest rate of 12 percent.

- Distribution of all additional equipment, personnel and other costs over all vehicles in the program.

A detailed methodology for estimating costs is presented in Appendix B. Again because it is likely that your program will differ from the examples provided, it is recommended that you use the methodology contained in Appendix B to determine the exact cost impact of adding the inflation check to your program.

Example No. 1: Delaware

This is an example of a centralized safety-only inspection program with a platform brake tester. It is typical of centralized safety inspection programs currently planning the addition of an emissions test to their program. As shown in Figure 13, the lane layout of these facilities consists of three stations as follows:

- The first station is vehicle check-in and wheel alignment. This is where the inspector checks the motorist's registration certificate against the vehicle license plate, prepares an inspection card, and checks the vehicle's horn, windshield wipers and lights for proper operation. Vehicle front end alignment is also checked at this station using a scuff gauge, and all the glass areas on the vehicle are checked for cracks.

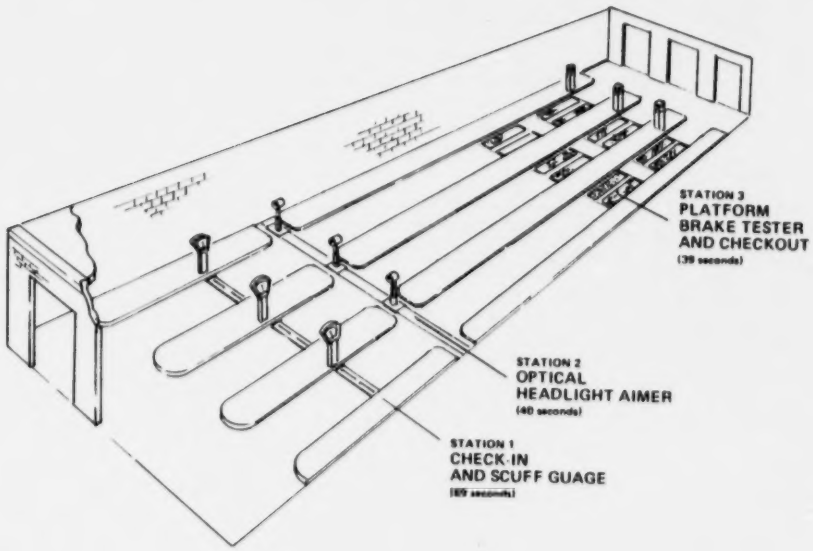

FIGURE 13. Delaware Centralized Safety Lane

- At the second station headlamp aim is checked using a track mounted optical headlamp aimer. Vehicle mileage is also checked at this station and recorded on the inspection card.

- At the third and final station, the vehicle's service brakes are tested, and the results of the inspection are provided to the motorist. In testing the vehicle's service brakes, a platform brake tester is employed.

The inspection employs three inspectors and in total takes slightly over 3 minutes. Maximum lane throughput is approximately 52 cars per hour (60 minutes divided by the time at the first Station --1.15 minutes). Delaware motorists presently do not pay a separate inspection fee. Rather the cost of inspection is included in their annual registration renewal fee.

Other jurisdictions with centralized safety-only inspection programs include the City of Chatanooga, Memphis, New Orleans, Florida's Orange, Duvall, Broward and Dade counties, and the District of Columbia. Of these

jurisdictions, Dade County, Florida and the District of Columbia have roller brake testers in lieu of platform brake testers. Other than this difference, the characteristics of these programs are similar to those just described for Delaware.

The best location for the tire pressure check in the Delaware lane would be Station 1, ideally prior to the vehicle running over the scuff gauge. Inflation at this point would not interfere with any other operation and the vehicle would be located there longer than at any other station. In addition, proper tire inflation could improve the efficiency of the brake test at Station 3. However, throughput would be significantly reduced if only one additional inspector was added. Thus, tne only feasible option for a Delaware type lane with similar tests would be to inflate the tires using two inspectors (one on each side of the vehicle). By adding two additional inspectors to Station 1, tire pressure can be checked on all four wheels in about one minute. The incremental cost of performing this test if distributed over all vehicles would be about $.89.

If Delaware converts its safety lane to a safety-emissions lane by adding emissions inspection at Station 2, then tire inflation could still take place at Station 1 without difficulty. Adding a tailpipe emissions test to Station 2 would require one additional inspector and would cost an additional $0.52.*

Example No. 2: Arizona

This is an example of an emissions-only centralized inspection program. With the exception of Oregon, it is typical of other existing and planned emissions-only inspection programs, although unlike Arizona most of these other programs will not have dynamometers. As shown in Figure 14, each lane consists of three stations as follows:

- Vehicle Check-in (Station 1). At this station, the inspector obtains vehicle registration information from the motorist and keys this information into the CRT unit. The inspector also collects the inspection fee and completed repair form in tne case of a reinspection.

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* U.S. Department of Transportation, An Evaluation of Existing Motor Vehicle Diagnostic Inspection Concepts, Volume V, prepared by Booz, Allen and Hamilton, June 1981, Contract No. DTN H22-80-C-05018.

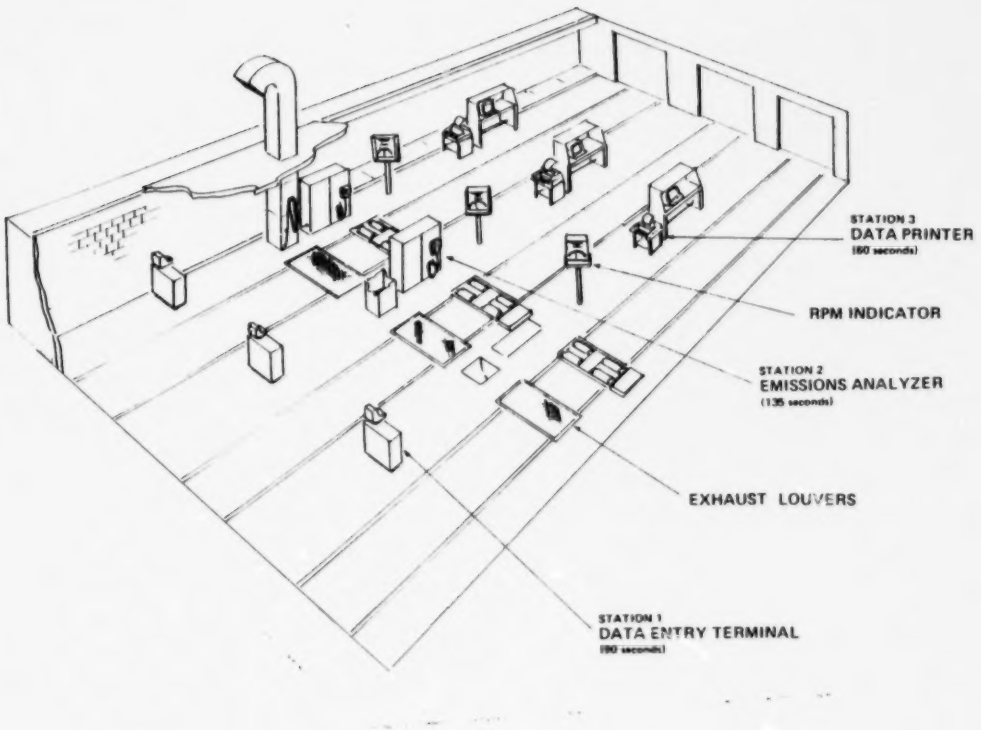

FIGURE 14. Arizona Emissions Inspection Lane

- Emissions Test (Station 2). At this station, the vehicle undergoes an emissions test. The test consists of sampling the exhaust gases of a vehicle using an infrared emissions analyzer while the vehicle is idling. However, if the vehicle fails this test, it is then preconditioned at 30 miles per hour while loaded on a dynamometer and retested at idle. Programs other than Arizona will accelerate the engine to 2500 rpm and then retest at idle. This avoids the need for a dynamometer.

- Vehicle Check-out (Station 3). At this station, the inspection results are printed out and a copy is given to the motorist.

The total inspection involves three inspectors (one per station) and takes approximately 5 minutes per vehicle. The maximum throughput of the lane is 27 vehicles per hour, and the cost per vehicle is $5.44.

Like Delaware the best location for the tire inflation check given this type of facility layout is Station 1.* Inflation at this station would not interfere with other operations. One additional inspector would be required, and there would be no impact on throughput. The incremental cost per vehicle would be the additional inspector's salary plus the annualized costs of the tire inflation equipment** -- approximately $0.71.

Example No. 3: New Jersey

This is an example of a typical centralized safety plus emissions program operated by State personnel. A schematic diagram depicting the layout of a typical lane in a New Jersey facility is shown in Figure 15. As shown, a typical lane consists of five stations as follows:

- Station 1: Vehicle Check-in and Emissions Test. At this station the inspector checks the vehicle registration, fills out the inspection card and performs an idle emissions test for HC/CO.

- Station 2: Scuff Test. At this station the vehicle's front end alignment is checked using a scuff gauge. In addition, the vehicle's windshield wipers, glazing, stop lights and turn signals are checked.

- Station 3: Front End Lift. This station involves a test of the vehicle's steering and suspension system. Steering lasn and play are also checked.

- Station 4: Headlamp Aim. This station involves a test of the vehicle headlamp aim using a track mounted optical headlamp tester. Both left and right, high and low beams are tested.

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* It could also be added to Station 3 without any impact on throughput, however it is best to add it to Station 1, especially for those states planning loaded mode testing due to the safety considerations associated with using a dynamometer.

** Arizona stations already have compressed air equipment to operate the dynamometers. This would reduce the capital requirements.

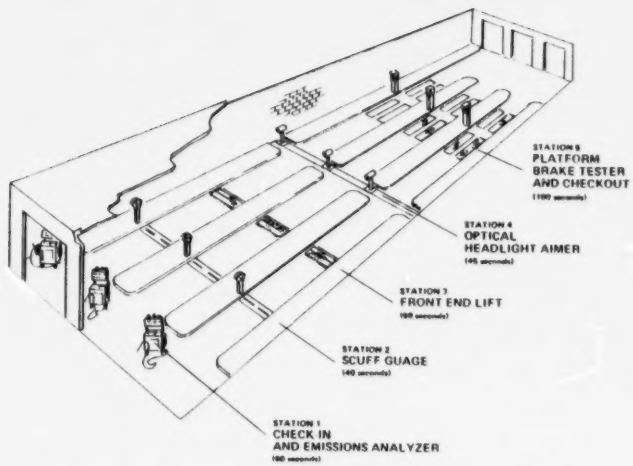

FIGURE 15. New Jersey Safety and Emissions Lane

- Station 5: Brake Test and Vehicle Checkout. At this final station, the vehicle undergoes a platform brake test. In addition, the parking brake and brake pedal reserve are also checked. Upon completion of these tests, the motorist is given the results of the inspection, and a sticker indicating the results is affixed to the windshield.

The total inspection as described above involves 5 inspectors and takes about 5 minutes per vehicle. The maximum throughput of each lane is about 36 vehicles per hour. The cost of the inspection is set by statute and is currently $2 per vehicle.

Again the best location for the tire inflation test (as in the other two examples) is Station 1, although the test can also be easily accomodated at Station 4 without any impact on throughput. Station 1 is recommended because it increases the accuracy of the scuff and platform brake tests (Stations 2 and 5).

The test would require an additional inspector and would cost about $0.71 per vehicle.

Example No. 4: Washington State

Washington state is planning to operate an emissions-only inspection lane with only one station and inspector at each lane. At this station a fee will be collected and the vehicle registration number input into a computer. The emissions will then be checked. The whole procedure should take about two minutes.

Adding tire inflation to a lane of this type would require one additional inspector working simultaneously with the emissions inspector. Since the test time at the facility is two minutes, the cost of the additional inspector will be about the same as in example number 2, $.71.

Checking Tire Pressure and Inflating Tires if Necessary in Decentralized Programs

Unlike centralized inspection facilities, maintaining a constant throughput is not a central criterion for the addition of a tire inflation check to decentralized facilities. In most decentralized inspection facilities, the inspection is performed by one person. Depending on the type of inspection and the items inspected, the time ranges from 5 to 45 minutes, and the cost per vehicle ranges from $2 to $15.

In general, tire inflation in decentralized programs should pose no particular difficulty. Most facilities that can perform an emissions or safety inspection normally would have the compressors and gauges necessary to inflate tires. The time requirement to inflate the tires, however, may be somewhat longer than for centralized facilities due to the inefficiency of decentralized facilities compared to centralized facilities, but a time of two minutes would be reasonable.

Thus, given the following assumptions, a tire inflation check could be added to a decentralized inspection program for about $1.00:

- All inspections would be conducted by the same person.
- Equipment if not already present would be amortized over a five-year period at an annual interest rate of 12 percent and would be completely amortized after five years.

- The total cost of performing any additional tests including the amortized cost of equipment would be passed onto the consumer.

- The average licenced inspection facility would conduct 1,500 inspections a year, about six per day, and that the shop hourly service rate would be $30 per hour.

A detailed methodology for calculating the cost impact of adding a tire inflation check to a decentralized inspection facility is contained in Appendix B.

The above assumptions were made to illustrate the likely cost impact of adding a tire inflation check to a decentralized inspection facility. Because it is likely that your program differs from the assumptions we have made here, it is recommeded that you use the methodology contained in Appendix B to determine the exact cost impact of adding a tire inflation test to your program.

Checking Pressure Without Inflating Tires in Centralized and Decentralized Programs

Some States may wish to add a less costly tire check to their programs. One concept that would add only pennies per vehicle to the cost of a program is based on a simple pressure measurement of one tire. An inspector with 15 or 20 seconds of slack time could measure the pressure on one tire and report to the motorist if the reading was low.

The motorist would be given appropriate consumer information (see Chapter V) and encouraged to inflate his or her tires to the proper level at a series of tire pressure towers located conveniently outside the facility or in a separate bay. While this approach would be less expensive than actually inflating a vehicle's tires, no benefits can safely be assumed as a result of the pressure checks since no inflation takes place. Also, since only one tire is checked, many vehicles with low tires may not be detected at all. However, some of the consumer information benefits indicated in Table 7 may still be achieved with this type of approach.

LIABILITY ISSUES

Contractors or states operating inspection programs may be concerned about potential liability claims, both legitimate and frivolous, if their employees inflate tires. Claims could be associated with tire failure, tire damage or accidents allegedly caused by vehicle handling problems. While

the material outlined in Chapter II and the recommendations made in this chapter should provide for safe program operation, the possibility still exists that a particular vehicle may at some time experience problems which could be related to the tire inflation. States may consider several methods to reduce the risk or impact of such claims:

- Obtaining the owner's consent before inflating tires
- Emphasizing in the consumer information literature that the motorist should check his vehicle's tire pressure regularly
- Not inflating tires when the correct tire pressure cannot be determined (for strategies 1 and 2) or where there is doubt whether the vehicle should be included or excluded from the program (strategy 3).
- Careful training of inspectors
- Adequate insurance coverage
- Set procedures for processing any claims.

V. METHODS OF MAINTAINING PRESSURE AFTER INSPECTION

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As discussed in detail in Appendix A, typical tires lose one-half to one psi per month. A large part of this pressure loss is due to air permeating through the tire body. In addition, a vehicle's tire pressure will change by about 1 psi for every 13 degrees Fahrenheit of temperature change. Thus, tire pressure should be checked regularly; the Tire Industry Safety Council recommends that tire pressure be checked at least monthly.

Tire pressure checks incorporated into emissions, safety or combined safety and emissions inspection programs will occur once or, in a few cases, twice a year, not frequently enough to ensure motorists are maintaining proper tire pressures on their vehicles. Thus methods of encouraging motorists to maintain proper tire pressure throughout the remaining part of the year following inspection are required. This chapter describes such methods.

LOW TIRE PRESSURE WARNING INDICATORS

One method is through the use of low tire pressure warning devices. Low tire pressure warning devices have been on the market for a number of years. These devices generally are attached to the valve stem of each tire and provide a visual signal when the tire pressure drops below a set value. Prices around $1 to $3 per wheel are typical.* With the use of these trigger mechanisms, the vehicle owner needs to only visually inspect each wheel to see if the tires are inflated properly.

In August, 1981, Consumer Reports reported on a test of a low tire pressure warning device made by Brookstone Company in Peterborough, N.H. The device was tested on several vehicles for up to 1200 miles of use. The magazine reported reliable and accurate operation of the product.

The National Highway Traffic Safety Administration, up until recently, was considering a proposal which would

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* Prices would be lower if the devices were purchased in large quantity for distribution by States. Electronic warning systems cost substantially more, usually $25 or more per wheel.

require all motor vehicles to have a low tire pressure warning system.* A review of the comments submitted by tire manufacturers and tire organizations was made to obtain insights as to the effectiveness of these devices.[22] Based on this review, it was found that industry experience with on-tire devices is in general quite negative. For instance, the Rubber Manufacturers Association stated:

> "No low pressure warning device that we know of has ever met the criteria of high reliability and affordable costs necessary to be a useful addition to passenger cars and trucks.[23]"

Rolls-Royce stated:

> "To date, systems evaluated by Rolls-Royce have not proved reliable over long periods of general system inactivity. This is a worrying feature as the required provision of a warning system immediately dilutes the user's responsibility for checking pressures regularly.[24]"

Thus, while tire pressure warning devices can help a motorist check tire pressure more easily, periodic checks (one a month) must still be made to insure that the device is operating properly.

A new trigger device that replaces the regular tire valve is supposed to be much more reliable than currently available tire pressure warning devices. (See Figure 16). It may soon be marketed by Schrader. However, this device can only be installed upon a tire change.

Given the above findings, State inspection programs, as a minimum, should inform motorists that the use of low tire pressure warning devices do not preclude them from periodically checking tire pressure. The devices may make pressure monitoring easier, but they do not eliminate the need for all precautionary checks. If new devices, such as the valve-replacement system, become available and are shown to be reliable, these can be recommended as replacement valves when new tires are purchased. Even then, motorists should still be encouraged to check tire pressure at least once a month, especially if the automatic devices are set to trigger at several psi below the manufacturer's recommended pressure.

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* The proposal was dropped by the Reagan Administration.

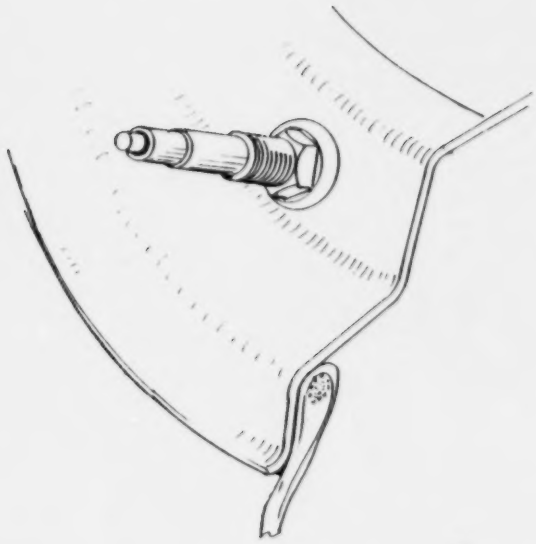

FIGURE 16. Low Tire Pressure Warning Device That Replaces The Tire Valve

CONSUMER INFORMATION

Another method of encouraging motorists to periodically check tire pressure is through the distribution of consumer information on tire maintenance. A consumer information program could easily be incorporated in a State motor vehicle inspection program. For example, a consumer information program could take either of the following two approaches:

- It could take the form of booklets or pamphlets that are distributed to motorists either upon entering or leaving the inspection facility.
- It could take the form of wall charts that the motorists could read while waiting for the inspection.

A number of booklets oriented towards consumers on tire maintenance are available from the Tire Industry Safety Council in Washington, D.C. free of charge.*

* A modest fee would most likely be charged if large quantities of booklets were ordered.

Regardless of the approach taken, the following is a list of some of the major points that should be stressed in any information program on tire maintenance that is oriented toward consumers:

- Underinflation has several detrimental effects. These include:
  - Reduced tire life
  - Reduced fuel economy
  - Increased chance of blow outs
- Proper inflation can be found on the tire sticker in the car or the owner's manual.
- An accurate tire pressure gauge should be purchased. These cost only $2 to $3.*
- Tire pressure should be checked at least monthly and before long trips.[25]
- When tire pressure is checked, make sure tires are "cold" or have been driven less than a mile. Pressures typically rise three or four pounds per square inch (psi) when hot. If it is necessary to add air to a hot tire, inflate it three or four psi above the recommended pressure. The tire should be rechecked when cool and readjusted if necessary.[26]
- Tire pressures can generally be increased 2 to 3 pounds to improve fuel economy and tread life without significantly affecting vehicle handling. Higher pressures will further improve fuel economy and tire tread life, but the motorist should do this with caution since the handling characteristics and ride of the vehicle may change. A motorist wishing maximum economy could inflate all tires to the maximum sidewall pressure allowed realizing that a slight adjustment to changed handling may be required. If front to rear pressure differentials specified by the vehicle manufacturer are maintained any changes in handling will be reduced. Do not exceed the limit molded on the tire sidewall when the tire is cold (this limit however can be exceeded by 3 to 4 psi when the tire is hot).

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* Prices would be lower if a state purchased large quantities of gauges and resold them to the public. Since some cheap gauges are inaccurate, a state may want to recommend certain gauges it knows are accurate. (See Consumer Reports, February, 1980).

- Make sure all tire valves and extensions where possible are equipped with valve caps to keep out dirt and moisture. Installing a new valve assembly is good insurance whenever a tire is replaced.[27] New valve assemblies with a special trigger to alert the driver when tire pressure is low can be installed and should help improve tire maintenance.

AVAILABILITY OF COMPRESSED AIR FOR PUBLIC USE

In recent years there has been growing concern over the availability of compressed air for public use. Many service stations have switched to self-service operation and have eliminated air towers or hoses for use by the public. Table 10 shows the number of motorist service facilities of different types where motorists should be able to inflate tires, according to a major manufacturer of air towers.[28] According to this manufacturer, nearly one-half of the service facilities do not have compressed air with gauges or a tire inflation capability. Further investigation by the Department of Energy indicates that a considerably smaller number actually have accessible, working air towers for the public. Many towers are broken or inaccurate due to poor maintenance by station owners.

TABLE 10. Vehicle Service Facilities

Facility Type	Number of Facilities
Full Service	76,700
Split Island	38,600
Self-Service	24,200
Convenience	13,100
Mini-Service	5,200
Truck Stop	2,400
Car Wash	2,400
Car Care	9,600
TOTAL	172,200

Source: Reference 28.

Recently, a number of facilities that normally would not have had the large compressors required in service station operation (for lifts and power tools) have been

able to offer compressed air to the public by purchasing relatively small, inexpensive compressors attached to coin operated pressure towers. The increase in these systems, however, is only slightly mitigating the general problem of compressed air availability.

Thus, given the declining number of service stations with air, other useful services an inspection facility could perform to encourage the public to maintain the proper tire pressure on their vehicles include the following:

- Provide information on the location of tire pressure towers convenient to the motorists' residences
- Provide tire pressure towers at inspection facilities
- Encourage the installation or repair of tire pressure towers at other facilities.

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APPENDIX A
CALCULATION OF FUEL ECONOMY AND TREADWEAR BENEFITS

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CALCULATION OF FUEL ECONOMY AND TREADWEAR BENEFITS

This appendix presents the methodology and assumptions employed to calculate the fuel economy and treadwear benefits summarized in Chapter I. Three elements are needed to calculate fuel economy and treadwear benefits:

- The distribution of tire pressure of in-use vehicles compared to recommended pressure
- The distribution of tire pressures after the inflation program
- The change in pressure with time

Each is described below followed by a detailed calculation of the effect of inflation pressure on fuel economy and treadwear.

TIRE PRESSURES OF IN-USE VEHICLES

Three sources were found which provided distributions of in-use tire pressures. The three sources are presented in Table A-1. The EPA data was taken from the 1977 emission factors program and is from six cities:

- Chicago
- Houston
- Phoenix
- St. Louis
- Denver
- Washington D.C.

Thus the EPA study data represents a broad cross section of the different climates and driving conditions in the U.S.[31]

Tests conducted by EPA were also selected on the basis of make and model year to give a representative sample of U.S. vehicles-in-use. Tests were all made at a uniform cold temperature of 76°F and corrected to reflect the mean outside temperature for the month and location of the test.

Based on the measurements taken, mean front pressure was found to be underinflated by 1 psi and mean rear pressure was low by 2.6 psi. Of the underinflated tires, mean front underinflation was 4.1 psi, mean rear underinflation was 4.9 psi, and mean overall underinflation was 4.5 psi.

The NHTSA data is a compilation of tire pressure distribution data provided by Uniroyal, Inc., and three AAA clubs around the country. The figures were gathered between 1973 and 1976.[32] The mean pressure according to this survey was low by 0.2 pounds.

TABLE A-1. Percent of Tires Below and Above Manufacturers Recommended Pressure

Amount Below Manufacturers Recommended Pressure (psi)	Percent of Tires Measured				
	EPA			Viergutz	
	Front	Rear	NHTSA	Winter	Summer
1	8.8	8.8	8.2		
2	10.0	9.2	9.1		
3	9.6	8.7	7.3		
4	7.5	9.5	5.3		
5	5.8	8.3	3.2	12	16
6	4.9	6.3	3.4	7	12
7	3.1	4.7	2.1		
8	2.3	3.5	2.1		
9	1.6	3.4	0.9		
10	0.87	2.1	1.6		
11	0.86	1.0	0.5	14	8
12	0.41	1.4	0.45		
13	0.15	0.66	0.25		
14	0.25	0.36	0.12		
15	0.15	0.20	0.12		
16	0	0.15	0.05		
17	0.05	0.05	0.02		
18	0.05	0.10	0.05		
TOTAL (Percent)	56.6	68.4	44.76		
Average Low	4.13	4.87			
Amount Above Manufacturers Recommended Pressure (psi)	Percent of Tires Measured				
	EPA			Viergutz	
	Front	Rear	NHTSA	Winter	Summer
0	9.4	8.5			
1	8.0	6.6			
2	5.9	4.5			
3	5.4	3.1			

The Viergutz data, part of which was discussed in Chapter 1, was derived from measurements in parking lots in Chicago during both the summer and winter. The vehicles were immobile for at least three hours before the test. Mean winter pressure was low by about 2.5 psi and mean summer pressure was low by about 0.8 psi.

The Viergutz and EPA data are in reasonably good agreement. The NHTSA data shows the same general trend but indicates less underinflation. Analyses presented in the remainder of this chapter are based on use of the EPA data. The EPA data was selected for use because it is closest to being representative of all vehicles in the United States throughout the year.

DISTRIBUTION OF TIRE PRESSURES AFTER AN INFLATION PROGRAM

As mentioned at the beginning of this chapter, three elements are needed to calculate fuel economy and treadwear benefits, one of which is the distribution of tire pressures after the inflation program. In calculating the fuel economy and treadwear benefits presented in this report, three inflation strategies were analyzed as follows:

- Strategy 1: Inflate all tires to the vehicle manufacturer recommended pressures, adjusted for temperature. The inspector determines the manufacturer's recommended pressure by reading the information on the placard usually found on the door pillar. If the tires are hot the values are increased 3 to 4 psi.

- Strategy 2: Inflate all tires to 3 psi above the vehicle manufacturer's recommended pressures, adjusted for temperature. The inspector determines the vehicle manufacturer's recommended pressures and adds 3 psi. He makes sure the resulting pressures do not exceed the maximum stamped on the tire sidewall. If the tires are hot the pressure values are increased another 3 to 4 psi.

- Strategy 3: Inflate all tires to the maximum sidewall pressure, adjusted for temperature. The inspector determines whether the vehicle is on a list of models that should not be inflated in the program (because their vehicle recommended tire pressures are too different from the maximum sidewall pressures). If the vehicle is not on the list, the tires are all inflated to the maximum pressure listed on the tire sidewall. If the tire is hot, 3 to 4 psi is added to the pressure.

In the following sections, the general decline in tire pressure after vehicles are inspected and the fuel economy and treadwear benefits are discussed separately for each of these strategies.

CHANGE IN PRESSURE WITH TIME

Researchers at Exxon[34] Corporation have concluded that significant inflation pressure loss occurs in sound, properly mounted tubeless tires, under static or dynamic conditions, primarily by air permeating through the tire structure. The principal part of the tire that effects inflation loss of tubeless tires is the innerliner.

The rate of air loss for a typical in-use tire is difficult to determine since the loss varies by tire type. However, industry engineers have indicated that a decline of 1/2 psi per month is reasonable. Detailed survey data are not available.

Perhaps more critical to estimating the rate of pressure loss for tires is estimating the general decline in tire pressure after vehicles are inspected. For purposes of analysis, two "pressure loss over time" scenarios were considered:

- Scenario 1: A decline in mean pressure of 1/2 psi per month with no changes in motorist tire maintenance habits. Under this scenario, motorists would not change their present tire maintenance habits. Thus the consumer information program would have no benefit. The result would be that tire pressures would be allowed to decrease to the levels they were prior to the inflation program.

- Scenario 2: A decline in mean pressure of 1/2 psi per month followed by reinflation every two months by the motorist. This scenario represents a situation where motorists would be influenced by the consumer information part of the inflation programmed and would therefore change their tire maintenance habits (i.e., motorists would inflate their tires more frequently then they would normally do). As a result, the pressure loss over time would be significantly reduced compared to Scenario 1.

Given these two scenarios, the following sections describe the effects on mean fleet tire pressure of each inflation strategy. The results are summarized in Table A-2.

TABLE A-2
Increased Yearly Mean Fleet Pressure Due to Different Tire Inflation Strategies.

Strategy	Inflate to Manufacturers Recommendations*	Inflate to 3 psi Above Manufacturers recommendations*	Inflate to Maximum Sidewall Pressure*
Effect considering no benefit from consumer information	1.1	2.6	4.3
Effect considering a benefit of consumer information	2.5	4.7	6.8

* Adjusted for temperature.

Strategy 1: Inflate All Tires to The Vehicle Manufacturers' Recommendations, Adjusted for Temperature. According to the EPA data (Table A-1) the average underinflation of vehicles with underinflated tires is 4.5 psi. After inflation all these tires will be at manufacturer's recommended pressure and, after decreasing at 1/2 psi per month, the mean pressure would return to 4.5 psi under specification after nine months, assuming no benefit from consumer information. Over a year these tires would show an average inflation 1.69 psi higher than would have occurred without the inflation program.* Since the underinflated tires are 63 percent of all tires, the average increase in pressure for the year for all tires would be 1.1 psi.

If an effective consumer information program encouraged motorists to reinflate their tires every two months, then with a 1/2 psi per month pressure loss rate,

* It is assumed that the tires would be 4.5 psi higher than without the inflation program at the beginning of month one and decline linearly to 0 psi higher than without the program at the end of the month nine. In months ten, eleven and twelve the tires are assumed to be 0 psi higher than without the program.

the average pressure for the year for tires inflated in the program would be 1/2 psi below vehicle manufacturer's recommended pressure. This would be 4 psi above the level that would have occured without the inflation program. The average increase in pressure for all tires for the year would then be 2.5 psi. Thus the consumer information yields an additional 1.4 psi average pressure increase over the situation with no consumer information benefit.

Strategy 2: Inflate All Tires to 3 psi Above The Vehicle Manufacturer's Recommendations, Adjusted for Temperature.

With this strategy, instead of the average tire pressure being increased 4.5 psi for inflated tires as in strategy 1, the average increase would be 6.1 psi. This includes inflating all tires less than 3 psi above manufacturers specifications (about 84 percent of all tires, from Table A-1). With a decrease of 1/2 psi per month (the case of no benefit from consumer information), the average pressure of the inflated tires would return to the situation prior to inflation after 12 months, and the tires that were inflated would average 3.1 psi higher than they would have without the program. Since these tires are 84 percent of all tires, the average increase in pressure for the year for all tires would be 2.6 psi.

With an effective consumer information program resulting in motorists reinflating their tires evey two months to the pressures used in the inflation program, then with a 1/2 psi per month pressure loss rate, the average pressure for the year for tires inflated in the program would be 5.6 psi above the level that would have existed without a program. Since these are 84 percent of all tires, the average increase in pressure for the year would be 4.7 psi. Thus, in this case consumer information could yield an additional 2.1 psi average pressure increase over the situation with no consumer information benefits.

Strategy 3: Inflate All Tires to Maximum Sidewall Pressure, Adjusted for Temperature.

To evaluate the effects of this strategy, one needs to know the distribution of vehicle-in-use tire pressures in an absolute sense rather than compared to manufacturers specifications. The EPA survey mentioned earlier[12] found that the average in-use tire pressure was 24.8 psi, 1.8 psi below the average pressure specification.

The EPA analyzed this data further and found that if all tires were inflated to 32 psi (cold pressure) unless already above that level, then the fleet average pressure would be 32.1 psi, 7.3 psi higher than before inflation. The EPA used 32 psi as the inflation pressure for the calculation since most of the tires had this as the maximum pressure indicated on the sidewall. In the situation with no consumer information impact, a decline of 1/2 psi per month for the fleet average pressure would result in an average pressure increase for the year due to the inflation program of 4.3 psi. (Virtually all the tires in the program would be inflated).

In the situation where effective consumer information influenced motorists to inflate their tires every two months, the overall increase in pressure for the year would be 6.8 psi (assuming a 1/2 psi decrease per month and consumers reinflating to the pressure used in the program). In this case the consumer information would yield an extra 2.5 psi average pressure increase over the situation with no consumer information benefits.

THE EFFECT OF INFLATION PRESSURE ON FUEL ECONOMY AND TREADWEAR

Table A-3 summarizes the results of different studies of the effect of inflation pressure on fuel economy and treadwear. The best estimate for the effect of tire pressure on fuel economy is the Grugett study result of .33 percent change in fuel economy per psi change for radial tires and the best estimate for the effect of tire pressure on treadware life is the Goodrich study result of 1.7 percent change in treadware life per psi for radial tires. Results are cited for radial tires because they are becoming the predominant tire on vehicles-in-use and will be the most frequently encountered tire in state inspection programs. In addition, these estimates more closely represent the composition and driving cycles of the vehicle-in-use fleet.

Combining these estimates with the average inflation changes computed in the previous section, one can compute the range of dollar savings provided by each inflation strategy. These savings and the calculation methodology are shown in Table A-4. In addition to the estimate noted above and in the previous section, the results presented in Table A-4 are based on the following:

- A total yearly fuel cost per vehicle of $996 based on:
  - An average fuel consumption per car of 664 gallons

TABLE A-3. Effects of Tire Pressure On Fuel Economy and Treadwear

Researcher	Effect on Fuel Economy	Effect on Treadwear
Grugett et al[6]	.33% per psi for radials urban--highway cycle, Chevy Nova	
Goodyear[7,8]	.30% per psi for radials, constant 45 mph, standard size car	
	.75% per psi for bias, constant 45 mph, standard size car	
Taylor[9]	.38% per psi for radials on city-highway cycle, .5% per psi at 30 mph cycle, GM X-car	
Goodrich[13]		1.7% per psi for radials
		2.4% per psi for bias*
Firestone[11]		1% per psi for truck tires at 2 psi under-inflation**

* A decrease in shoulder-crown wear ratio may somewhat reduce this benefit.

** The Firestone data is not linear and shows an average treadwear change of 2.5 percent per psi at 4 psi underinflation.

- A gasoline price of $1.50 per gallon

. A total yearly tire cost per vehicle of $66.70 based on:

  - An average tire cost of $50
  - An average tire life of 3 years

As shown in Table A-4, given these assumptions, the total benefit of an inflation program ranges from $4.82 to $28.72 depending on the type of inflation strategy and the amount of benefit realized from the consumer information program.

TABLE A-4. Summary of Fuel Economy and Treadwear Benefits by Inflation Strategy (Dollars Per Motorist Per Year)

Benefit Category	Inflate to Vehicle Manufacturer's Recommendations*		Inflate to 3 psi Above Manufacturer's Recommendations*		Inflate to Maximum Sidewall Pressure*	
	Without a Consumer Information Benefit	With a Consumer Information Benefit	Without a Consumer Information Benefit	With a Consumer Information Benefit	Without a Consumer Information Benefit	With a Consumer Information Benefit
Fuel Economy Benefit						
(1) Average Annual Fleetwide Increase in Tire Pressures Resulting from Inflation Program	1.1 psi	2.5 psi	2.6 psi	4.7 psi	4.3 psi	6.8 psi
(2) Percentage Improvement in Fuel Economy Per psi	.33%/psi	.33%/psi	.33%/psi	.33%/psi	.33%/psi	.33%/psi
(3) Annual Percentage Improvement in Fuel Economy (1 x 2)	.36%	.83%	.86%	1.58%	1.42%	2.24%
(4) Annual Percentage Reduction in Fuel Consumption**	.36%	.82%	.85%	1.53%	1.40%	2.19%
(5) Annual Fuel Costs per Car***	$996	$996	$996	$996	$996	$996
(6) Annual Fuel Cost Savings (4 x 5)	$3.59	$8.17	$8.47	$15.24	$13.94	$21.81
Treadwear Benefit						
(7) Percentage Improvement in Treadwear Life Per psi	1.7%/psi	1.7%/psi	1.7%/psi	1.7%/psi	1.7%/psi	1.7%/psi
(8) Annual Percentage Improvement in Treadwear (1 x 7)	1.87%	4.25%	4.42%	7.99%	7.31	11.56%
(9) Annual Percentage Improvement in Tire Costs**	1.84%	4.08%	4.23%	7.40%	6.81%	10.36%
(10) Annual Tire Costs per Car****	$66.70	$66.70	$66.70	$66.70	$66.70	$66.70
(11) Annual Tire Cost Savings (9 x 10)	$1.23	$2.72	$2.82	$4.94	$4.54	$6.91
TOTAL BENEFIT	$4.82	$10.89	$11.29	$20.18	$18.48	$28.72

* Adjusted for temperature.
** If the MPG or miles per tire benefits is X, then the yearly consumption benefit is x/(1 + x).
*** Based on an average fuel consumption per car of 664 gallons and a gasoline price of $1.50 per gallon.
**** Based on an average tire cost of $50 and an average tire life of 3 years.

APPENDIX B
METHODOLOGY FOR ESTIMATING CHANGES IN PROGRAM COSTS

APPENDIX B
METHODOLOGY FOR ESTIMATING CHANGES IN PROGRAM COSTS

This appendix presents the general methodologies for estimating the cost impacts of changes in inspection programs. The first section discusses estimating procedures for centralized lanes and the next section discusses cost estimating in decentralized programs.

METHODOLOGY FOR ESTIMATING THE EFFECTS OF PROGRAM CHANGES ON COSTS PER VEHICLE IN CENTRALIZED PROGRAMS

This section presents certain procedures for rapidly estimating the effects of program changes on the cost per vehicle of a centralized inspection program. The calculations apply to a dedicated centralized facility where all program costs are covered by the vehicle test fee. The first subsection below presents rules-of-thumb for rapid calculations where many parameters of a typical program are assumed. The second subsection below presents more detailed formulas that can be used for more precise calculations.

Rule-of-Thumb Calculations

There are three primary possible effects of a modification to an existing lane: capital investment, a change in labor requirements and a change in throughput. Figures B-1 through B-3 present graphs that demonstrate the implications of these changes. Figure B-1 shows the change in cost per vehicle of adding an additional inspector to lanes at different total yearly paid throughput. Total paid throughput is the total number of vehicle tests per lane on an annual basis from which fees are collected or assessed. The method illustrated is applicable to all systems, regardless of their efficiency. Figure B-2 shows the change in cost per vehicle for each additional $1,000 of capital investment in a lane. Figure B-3 shows the increase in cost as a percent of base fee for various percentage changes in throughput. The effect of a change in throughput should be calculated with a base fee that already reflects any changes in cost due to labor or capital. Figures B-1 and B-2 reflect the following assumptions: five-year capital depreciation, 12 percent interest, 10 percent profit on all annual costs, inspector wage of $11,000, 30 percent fringe cost, 15 percent general and administrative charge on labor costs, and two months of training for each new inspector.

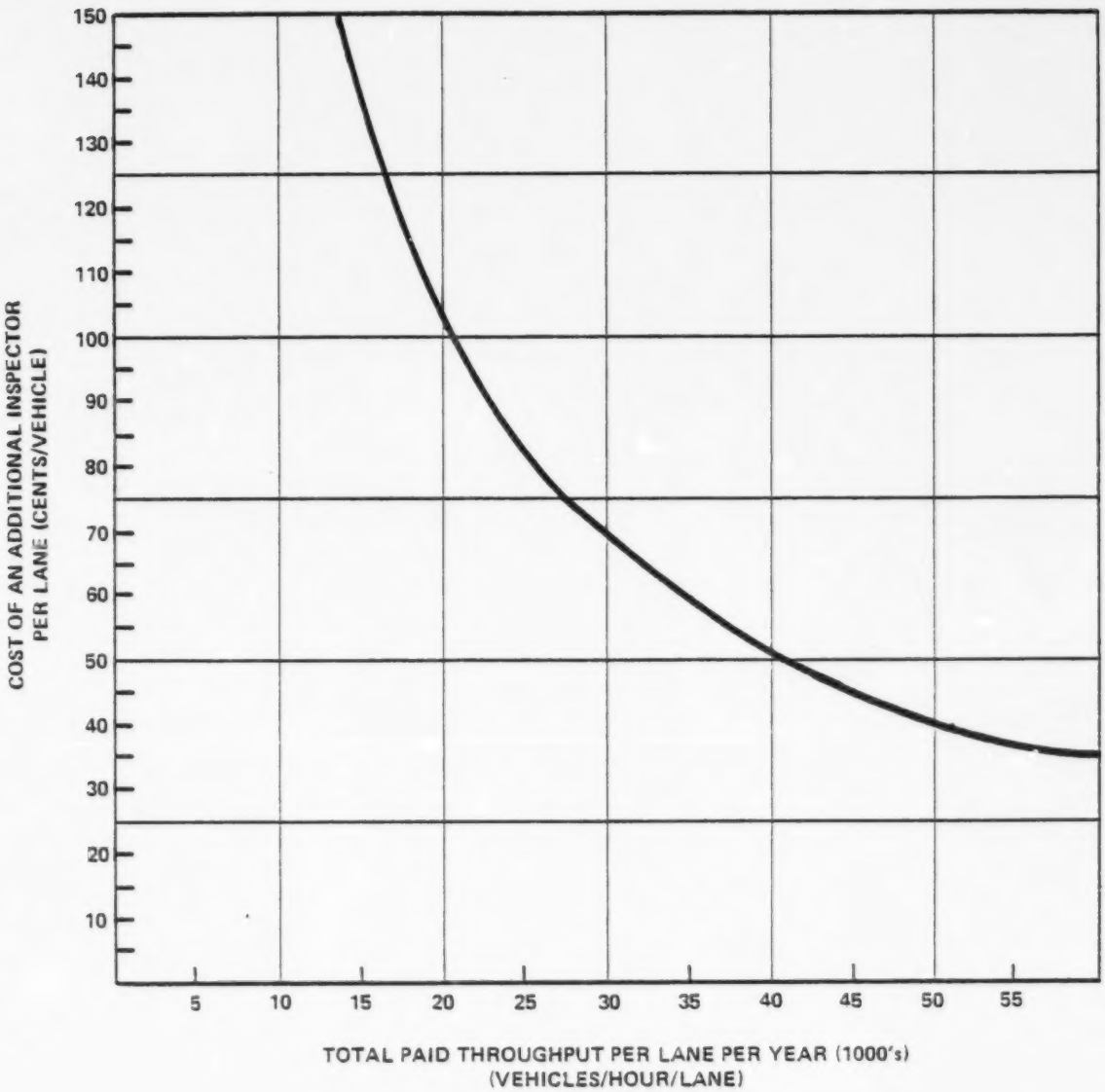

FIGURE B-1. COST OF ADDING AN INSPECTOR*

* Assumes wage of $11,000, fringe at 30 percent, G&A at 15 percent, profit at 10 percent, 2 months training, and capitalization over five years at 12 percent interest. For non-profit programs, see explanation on page B-5.

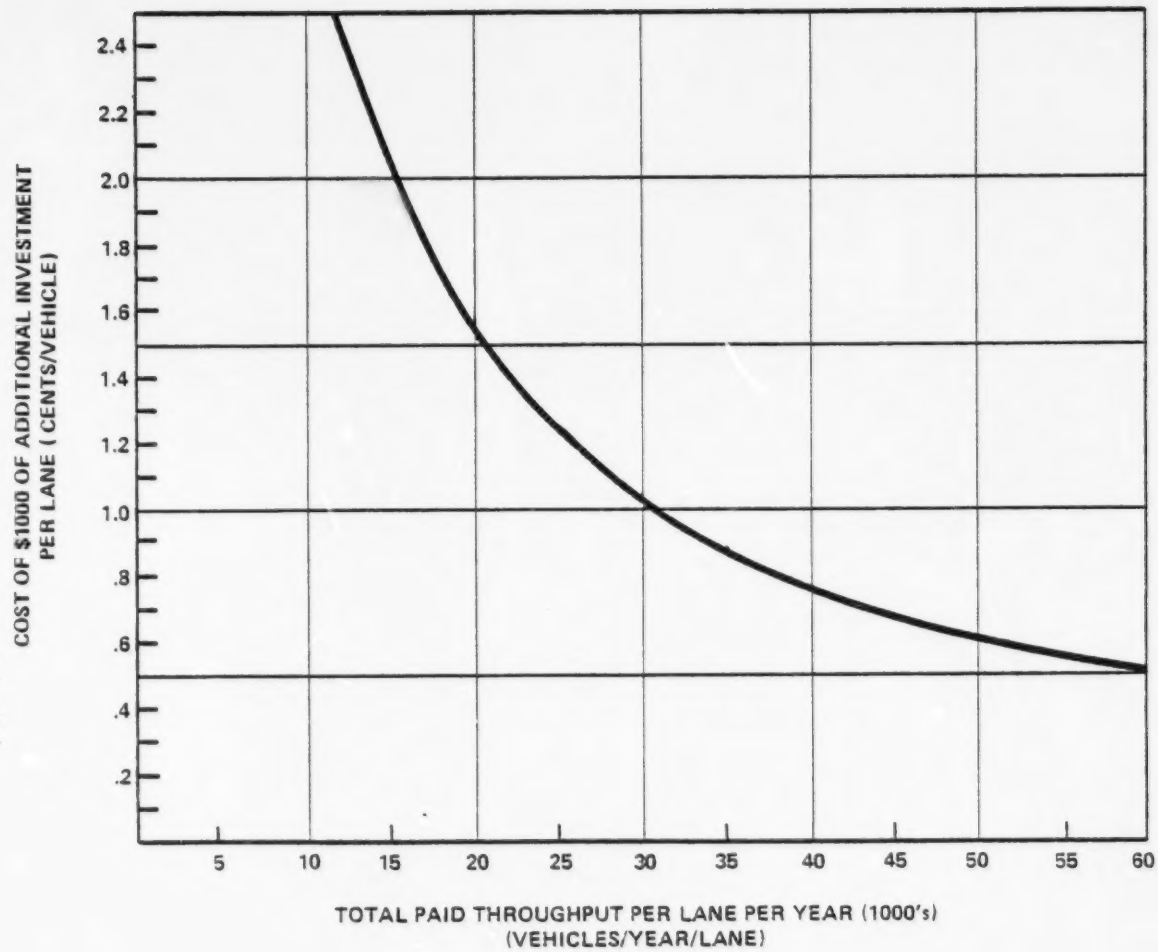

FIGURE B-2. COST OF ADDITIONAL INVESTMENT*

* Assumes five-year capital depreciation, 12 percent interest, 10 percent profit on annual charges.

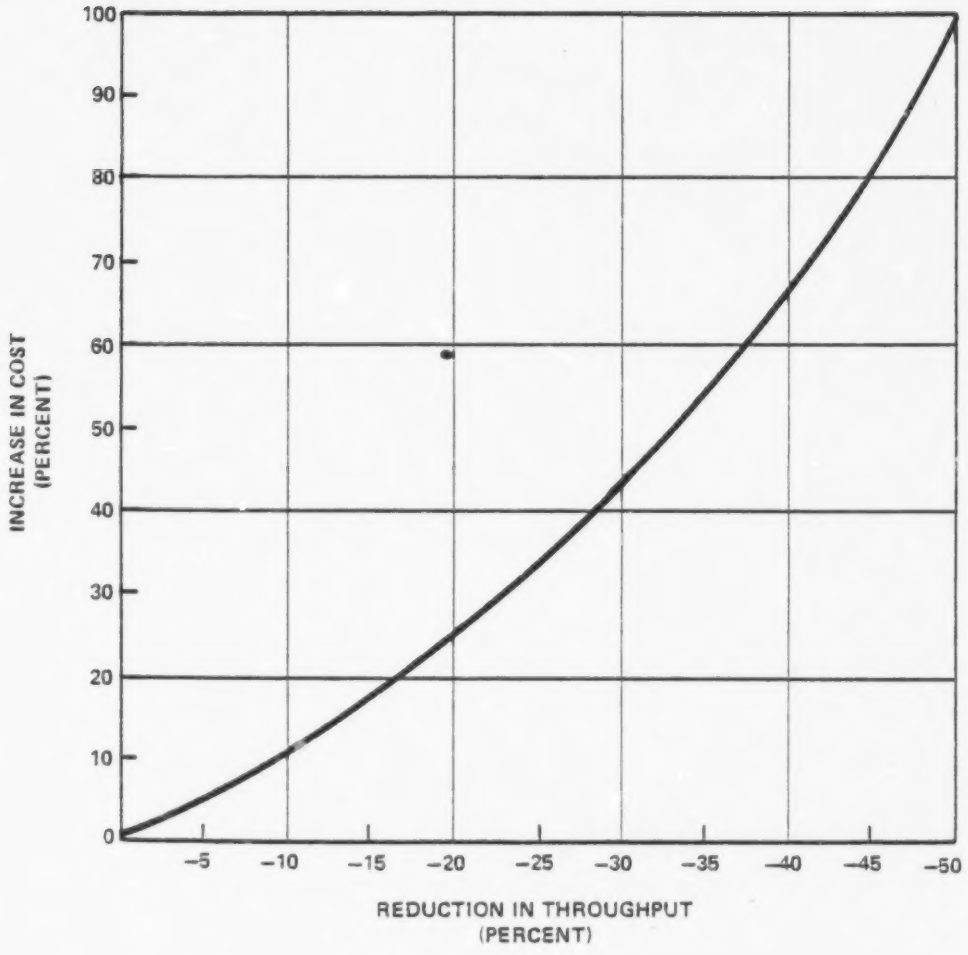

FIGURE B-3. COST OF A CHANGE IN THROUGHPUT

The following example illustrates how these graphs can be used.

Example. A centralized inspection program is considering a change that will result in an additional $10,000 of capital investment in each lane, one new inspector in each lane and a decrease of throughput of 10 percent. The system currently has 100 lanes and tests 3 million vehicles per year that pay $10 only upon initial testing. The $10 currently covers all program costs. The assumptions of Figures B-1 and B-2 are reasonable for this system. What should the new fee be to keep the program self-supporting?

Answer. Since there are 3 million paid tests in 100 lanes each year, the yearly paid throughput is 30,000 cars per lane. Examining Figure B-1, the cost of adding an inspector per lane is 69 cents per vehicle. Examining Figure B-2, the cost of $10,000 of investment per lane is 10.2 cents per vehicle. These two changes would increase the fee per vehicle from $10 to $10.79. Examining Figure B-3, the 10 percent reduction in throughput increases the fee per vehicle by 11 percent. Thus the $10.79 must be increased by 11 percent to $11.98, and the new fee should be $11.98.

Other Assumptions

To allow the use of other assumptions in the cost calculations, the following formulas for labor costs and capital costs are provided. The effect of a change in throughput (Figure B-3) is not affected by changes in the cost assumptions.

1. Cost of Adding $1,000 of Capital per Lane

$$\text{Change in fee (cents per vehicle) of adding \$1,000 of capital per lane} = \frac{1{,}000 \times \text{Capitalization Factor} \times (1 + \% \text{ Profit}/100)}{\text{TOTAL PAID THROUGHPUT PER LANE}}$$

The percent profit is the amount of profit a contractor would charge as a percent of annual costs. In Figure B-2, 10 percent is used so that (1 + percent profit/100) would be 1.10. In a state-run program profit would be zero, so that (1 + percent profit/100) would be 1.0.

Total paid throughput per lane is the number of vehicle tests per lane per year from which fees are collected. This number is the same as was used in Figures B-1 and B-2.

The capitalization factor converts a capital investment into a series of fixed annual costs that must be reimbursed. Table B-1 shows these factors for different interest rates, different program lengths and different depreciation periods. Typically, equipment would be depreciated in five years, buildings at the number of years the program is expected to run. Land is usually not depreciated. The factor used in Figure B-2 was .28, corresponding to 12 percent interest and five year depreciation.

2. Cost of Adding An Inspector to Each Lane

Change in fee (cents per vehicle) of adding one person per lane:

$$= \frac{\text{Wage} \times (1 + \% \text{ Fringe}/100) \times (1 + \% \text{ G\&A}/100) \times (1 + \% \text{ Profit}/100)}{\text{PAID THROUGHPUT PER LANE}} +$$

$$\frac{\text{Wage} \times (1 + \% \text{ Fringe}/100) \times (1 + \% \text{ Profit}/100) \times (\frac{2}{12} \times \text{Capitalization Factor})}{\text{PAID THROUGHPUT PER LANE}}$$

The wage is the base wage per year paid to the inspector. In Figure B-1 a wage of $11,000 was used.

The percent fringe is the percent of base wage that accounts for all fringe costs. In Figure B-1, 30 percent was used so that (1 + percent fringe/100) became $1.30.

The percent G&A is the percent of operating expenses used to account for general and administrative expenses. In Figure B-1, 15 percent was used so that (1 + percent G&A/100) became $1.15.

The capitalization factor is the same as described previously and is used to amortize the training costs over the program life.

3. Other Costs

In a more detailed calculation, one might wish to look at effects on utilities, property taxes, maintenance, supplies, etc. However, these costs would generally not change significantly with a lane modification. Also, costs of headquarters or other supervisory offices may increase beyond the 15 percent G&A already allowed for.

TABLE B-1. ANNUALIZED CAPITAL COST FACTORS*

Interest (%)		6		8		10		12		14		16	
Program Life (Years)		5	10	5	10	5	10	5	10	5	10	5	10
Depreciable Life (Years)	5	.24	.24	.25	.25	.26	.26	.28	.28	.29	.29	.31	.31
	10	.15	.14	.17	.15	.18	.16	.20	.18	.22	.19	.23	.21
	15	.12	.11	.14	.13	.15	.14	.17	.16	.19	.16	.21	.19
	NO DPR	.06	.06	.08	.08	.10	.10	.12	.12	.14	.14	.16	.16

*Calculations assume salvage value based on straight line depreciation. Based on formula:

$$FACTOR = \left(1 - \frac{\frac{DPR - PRL}{DPR}}{(1+INT)^{PRL}}\right) \times \left(\frac{INT\ (1 + INT)^{PRL}}{(1 + INT)^{PRL} - 1}\right)$$

Where:

INT = Interest rate
DPR = Depreciation period
PRL = Program life.

METHODOLOGY FOR ESTIMATING THE EFFECTS OF PROGRAM CHANGES ON COSTS PER VEHICLE IN DECENTRALIZED PROGRAMS

To estimate the impacts of adding different tests and equipment to a decentralized program, several pieces of information are required:

- Shop labor rate
- Equipment cost
- Method and rate of equipment amortization
- Time required to perform the test
- Number of inspections performed per shop annually.

Once this information is obtained, calculation of the impacts is relatively straightforward. Since the above information is likely to vary from shop to shop, it is recommended that you initially use "average" figures. Later you can perform a sensitivity analysis to determine the likely range of impacts by varying these average figures.

The following methodology assumes that all costs including the amortized cost of equipment and inspector labor time will be passed directly to the consumer in their entirety. In actual practice private garages do not recover all the costs of performing the inspection; rather the fee which is ultimately established is usually lower than the actual cost of inspection. The private garage performs the inspection "at a loss" in hopes that it will receive the potential repair business resulting from the inspection.

While there are no hard and fast rules for how much of a "loss" the private garage is willing to accept, our analysis of several existing programs indicates that this figure ranges between 20 and 40 percent of the true cost of inspection. Thus by multiplying the total per vehicle cost impact which will result by employing the methodology described below by a number between 20 and 40 percent, one can reasonably estimate the incremental fee a private gargage might be willing to accept to perform the additional tests.

The methodology consists of three steps as follows:

- Step 1: Given a specific test/equipment combination, determine the per vehicle labor cost by multiplying the per vehicle test time by the shop labor rate per the same unit of time.

- Step 2: Determine the per vehicle amortized equipment cost by first determining the annualized equipment cost and then dividing this cost by the annual number of garage inspections. Determine the annualized equipment cost using the following formula:

$$\text{Annualized Equipment Cost} = \text{Initial Equipment Cost} \times \frac{i(1+i)^n}{(1+i)^n-1}$$

where i equals the interest rate and n equals the depreciation period (typically five years). The above formula assumes the salvage value of the equipment is zero at the end of the depreciation period.

- Step 3: Determine the total per vehicle cost impact by summing the resuts of Steps 1 and 2. The impact on vehicle processing time is simply the per vehicle test time. There is no personnel impact since it is assumed that all inspections are performed by one inspector.

Using the above methodology, the impact of any test/equipment combination can be determined. By simply varying the input data (i.e., average figures you employed), the sensitivity of the impacts can also be determined. It should be noted, however, that the above methodology does not consider any additional state administrative costs that might be associated with the addition of a test/equipment combination. If such costs are anticipated, the per vehicle cost impact of these costs can be determined by dividing these costs by the total number of vehicle subject to inspection.